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Fabrication of Prepackaged Superalloy Honeycomb Thermal Protection System (TPS) Panels

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FOREWORD

This is an interim report on work being performed by Rohr Industries, Inc., - Design and Fabrication of Titanium Multiwall Thermal Protection System (TPS) - describing the Task V activities. Task V, Concept Development of prepackaged Superalloy Honeycomb Sandwich panels consisted of:

a. A material survey and preliminary design;

b. Fabrication of component and full sized panels for structural and thermal tests;

c. Thermal analysis;

d. Structural analysis;

e. Thermal and structural tests to verify the design analysis; and

f. Fabrication of 25 panels for delivery to NASA Langley Research Center for additional testing.

This program is administrated by the National Aeronautics and Space Administration Langley Research Center (NASA LaRC). Mr. John Shideler of the Thermal Structures Branch, Loads and Aeroelasticity Division, is the technical monitor.

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SUMMARY

A material survey was conducted to find suitable materials that could be used as a Thermal Protection System (TPS) for one hundred missions on entry vehicles where the temperature range is 810° to 1,366°K (1,000° to 2,000°F) and pressure loads do not exceed 13.8 kiloPascals (kPa) (2 PSI). A combination of INCONEL 617, TI-6Al-4V and silica fiber materials were selected to be used as a sandwich. A TPS panel was designed using the thermal requirements for Space Shuttle Body Point 1300 as representative design criteria. Thermal and structural analyses were performed. Component specimens and full size panels were fabricated and tested to verify the design. Comparison of analytical and test data substantiate the analysis methods and verify the thermal and structural performance of the panels.

After design verification tests, one array of twenty panels, an array of two panels, and three single panels were fabricated and delivered to NASA Langley Research Center for additional testing.

1/ INTRODUCTION

As part of a program to develop lightweight durable Thermal Protection Systems (TPS) for future space transportation systems, titanium TPS panels have been studied for application where surface temperatures do not exceed 1000°F (References 1 through 5). This report describes an extension of the program to develop TPS for the temperature range from 1000°F to 2000°F. The objective of the work reported herein (Task V, Contract NAS1-15646) was to survey high temperature materials and select a TPS material/configuration based on prepackaged superalloy concepts identified in References 5, 6 and 7, to analyze the selected design both thermally and structurally, and to fabricate and test specimens to obtain data for correlation with analysis. Finally, upon verification of the design, full-sized panels and arrays of panels were fabricated for delivery to NASA for additional testing.

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2/ DESCRIPTION OF CONFIGURATION

The design configuration is the result of various trade off studies performed on the original design supplied by NASA-Langley (see References 5-7). The trade offs involved the structural and thermal performance of the panel. The resultant design is shown in Figure 1-A.

The inner and outer layers of the panel are honeycomb sandwich. The original configuration called for dimpled core as used in the titanium multiwall concept. However, the use of honeycomb core was shown to be more efficient structurally and to be equivalent in thermal performance even though the honeycomb has a higher thermal conductivity. This is because the honeycomb core sandwich does not structurally require as much thickness as the dimpled core sandwich, and consequently there can be more fibrous insulation for a given panel thickness.

The side walls of the original design were slanted at 0.524 Radians (30 degrees) in an attempt to optimize thermal performance. Detailed investigation into this concept produced several objectionable features. First, since the center of pressure of the top layer of the panel did not line up with the centroid of the attachment clips, there was significant nonuniformity in the internal loading. Secondly, the sloped side walls were heavier and did not have the strength or stability of vertical sidewalls. Thirdly, finite element model studies revealed a thermal

kinematics problem between adjacent panels. With the sloped arrangement, adjacent panel sidewalls thermally grow and rotate into each other. Finally, a detailed thermal analysis showed the vertical sidewalls to have adequate thermal performance. As a result, the design configuration has vertical sidewalls which have corrugated flutes to provide stability and impede the flow of gases through the gap between panels during service.

The detail design Figure 1-A, employs a titanium 6Al-4V 4.32 mm (0.170 inch) thick honeycomb inner panel, a 7.11 mm (0.280 inch) thick Inconel 617 honeycomb outer panel with 12.7 mm (0.50 inch) thick Dynaflex and 35.31 mm (1.39 inches) thick Q Fiber Felt sandwiched between the two panels. The Inconel 617 honeycomb panel which was brazed includes two 0.13 mm (0.005 inch) thick skins, honeycomb core, and four side closures. The titanium 6Al-4V honeycomb panel which was Liquid Interface Diffusion (LID) bonded includes two 0.15 mm (0.006 inch) thick skins and honeycomb core.

The honeycomb core for the Inconel sandwich is 1/4 inch cell fabricated from 0.05 mm (0.002 inch thick) Inconel 617 foil. This foil thickness is the thinnest that can be brazed with the very aggressive braze alloy that was used. The cell size and face sheet thicknesses were determined by trade off studies which calculated the minimum weight of the sandwich system for the required strength. The critical strength parameter is intracell buckling. The core height is the minimum required to react the bending moment created by the pressure loads.

The honeycomb core for the titanium sandwich is 3/16 inch cell fabricated from 0.05 mm (0.002 inch) Ti-3Al-2.5V foil. This is the thinnest foil that can practically be LID bonded. The cell size, core height, and face

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LID bonding is a Rohr Proprietary process in which the part interfaces are plated with one or more element which when heated to the proper temperature will melt, creating a short time eutectic melt with the titanium causing a bond to occur across the interface.

sheet thicknesses were determined by the same methods as those for the Inconel sandwich. The results of all stress analyses are discussed in Section 7.3 "Structural Analysis of Full Sized Panel."

The Q-Fiber Felt and Dynaflex were sized based on the predicted temperature range between the honeycomb panels. The Inconel 617 honeycomb panel was sized based on an entry temperature of 1,366°K (2,000°F) and 2 psi external pressure load. The Titanium 6Al-4V honeycomb panel was sized based on the same entry conditions plus the concentrated load near each of the four corner attachment points.

The panels are normally attached to a vehicle by means of a bayonet and clip arrangement (see Figure 2). As shown, the bayonet goes into a clip on an adjacent panel and also through a vehicle clip. Thus each bayonet secures the forward edge of its panel, and the aft edge of the panel in front of it. The panel bayonets and clips are attached to the panels by diffusion bonding and the vehicle clips are mechanically fastened to the vehicle. The panels are installed in shingle fashion. Therefore, if a panel were damaged near the front of the vehicle, it would be necessary to start panel removal from the rear of the vehicle and remove an entire row to reach the damaged panel.

To have more flexibility in removal and replacement of panels on a vehicle, an alternate attachment concept was designed. It is a through-panel fastener concept and is used on a panel at the end of a row of panels. The through-panel fastener allows this end panel to be removed and access to be gained to the adjacent panels. As shown in Figures 1-A and 3, a sleeve structure with a removable cap is internally brazed to the panel and a bolt connects it to the vehicle substructure. The through-panel fastener was designed to transfer loads between the upper and lower panels and at the same time limit the through-panel thermal conductance. The conductance path is limited by the use of a plastic washer under the bolt head and by the small contact area between the bolt and lower panel. In addition, the fastener cavity is filled with fibrous insulation to limit direct radiation.

3/ DESIGN CONDITIONS

A Space Shuttle environment for body point 1300 was used as typical design criteria for this panel. The design point is located on the bottom centerline just aft of the cockpit. The design criteria for this panel included temperature and aerodynamic pressure environments for an ascent and a descent condition. These pressure loads and thermal gradients are tabulated in Table 1.

The ascent condition provided the maximum pressure load (ΔP) on the panel. This load was contractually set at 14 KPa (2.0 psi) ultimate. Accurate determination of a typical pressure load for the panel is difficult because such loads can be associated with complex surface pressure gradients which occur due to shock waves on the vehicle surface. However the 14.0 KPa (2.0 psi) agrees well with that derived during the Reference 7 study. This study included two areas which are also on the underbody of the shuttle and have temperature environments similar to BP 1300. One is designated Area II and is located on the lower aft fuselage. The other is designated Area III and is located on the main landing gear door. The associated surface temperature gradients for the 14.0 KPa (2 psi) design load was conservatively assumed to be the maximum one of either Area II or Area III. This turned out to be Area II and is shown on Page 2-9 of Reference 7 and Table 1 of this report.

The descent condition provided the maximum thermal environment and thermal gradient. The temperature and pressure data tabulated in Tables 2 and 3 were used to calculate the temperature distributions shown in Figure 4. The critical thermal gradient occurred at time = 500 seconds where the outer surface reaches its maximum temperature value of 1900°F. At this time, the inner surface is still relatively cool at 208°F so the maximum temperature gradient exists on the panel. Reference 7 study showed that there are not any pressure loads on the Area II and Area III panels during these elevated temperature exposures. The shock pressures are exerted after the panels have cooled down to near ambient temperature. These two conditions, providing separately the maximum pressure and thermal gradients on the panel, are used in the Section 7.3 structural analysis.

The effects of time at temperature were also considered during the test program and during the stress analysis. Basically, this consideration is that the panels during entry are exposed to 1256° to 1366°K (1800° to 2,000°F) environment for approximately 300 seconds during every flight or approximately 8 hours for 100 flights.

4/ MATERIAL SURVEY

Literature was searched to locate a suitable metal that would retain adequate strength at temperatures up to 1,366°K (2,000°F) for 100 hours. This selection was based on the fact that a 100-mission reuse requirement for TPS for a shuttle type vehicle represents a total life requirement on the order of 10 to 100 hours at elevated temperature.

At elevated temperatures, the short time mechanical properties (F_{tu}, F_{ty}) are still of importance in design, but time-dependent properties become the governing design consideration. Creep strength, metallurgical stability, and oxidation resistance are included in this category. The creep strength of an alloy will determine its high temperature load-carrying ability while oxidation will have to be accounted for by an increase in thickness to maintain the required load carrying capability for the total life. In addition to the above criteria, availability, cost and fabricability have to be taken into account in determining the most suitable alloy. Material in the following gauges were required for this task:

a. 0.051 mm by 102 mm wide (0.002 inch by 4 inches wide)
b. 0.076 mm by 330 mm wide (0.003 inch by 13 inches wide)
c. 0.127 mm by 330 mm wide (0.005 inch by 13 inches wide)

Four alloy families were considered. They are:

a. Precipitation strengthened (PH) super alloys
b. Oxide dispersed alloys
c. Refractory alloys
d. Solid solution strengthened alloys

4.1 PRECIPITATION STRENGTHENED (PH) SUPERALLOYS

Gamma prime, the main strengthening precipitate of Precipation Strengthened Superalloys, starts to become metallurgically unstable after short exposures to temperatures at or around 1,366°K (2,000°F). This instability (overaging or solutioning) is reflected in the degradation of high temperature mechanical properties. This family of alloys must therefore be excluded from consideration. Rene 41 (see Table 4), for example, has been considered in previous studies (Reference 5) as a potential TPS material. The solutioning temperature of Rene 41, however, is 1,338°K (1,950°F). Exposure of this material to 1,366°K (2,000°F) would thus result in a material with extremely low creep strength that would be totally unsuitable.

4.2 OXIDE DISPERSED (OD) ALLOYS

The OD alloys such as thoria dispered (TD) nickel, TD nickel-chromium, and MA 956 [Yttria (Y_2O_3) dispersed] have adequate 1,366°K (2,000°F) yield and creep strengths (see Table 4). However, use of these alloys may result in fabrication and availability problems. MA 956, for example, has only been rolled to 0.012 inch. The TD nickel alloys have over 12-month lead times and cannot be rolled down to the required dimensions indicated in Reference 3 at this time.

4.3 REFRACTORY ALLOYS

Refractory materials such as columbium, molybdenum, and tungsten alloys have more than adequate 1,366°K (2,000°F) yield and creep strengths. However, they are inherently difficult to use in fabrication processes, require a coating to protect them from oxidation at high temperature, and

they become brittle at room temperature. Due to the encountered difficulties, this family of alloys is usually considered as TPS material for temperatures above 1,366°K (2,000°F) only.

4.4 SOLID SOLUTION STRENGTHENED SUPERALLOYS

Solid solution strengthened alloys, as the name implies, receive much of their high temperature strength from solute refractory (chromium, molybdenum, tungsten) and cobalt atoms. These atoms strengthen by acting to retard dislocation movement. In addition, these alloys are also strengthened through carbide precipitation.

In selecting a suitable candidate TPS material, one of the most useful sets of data for comparison purposes is the 1,366°K (2,000°F) 100 hour 0.2 percent specific creep strength, which may be derived from the 100 hour 0.2 percent creep strength. Unfortunately, this data is not as readily available for all the potential solid solution strengthened superalloys as is the 1,366°K (2,000°F) 100 hour creep rupture data. The main set of data used in comparing the creep behavior of the differing alloys was therefore the creep rupture data.

A list of candidate solid solution strengthened superalloys is shown in Table 4. As creep strength to weight ratios are important for any high temperature aerospace component, the alloys in Table 4 are listed 1 to 10 in order of their 1,366°K (2,000°F) 100 hour creep rupture specific strength. 1,366°K (2,000°F) and 1,255°K (1,800°F) creep rupture (100 hour) and short time Ultimate Tensile Strength (UTS) results are also shown for comparison.

As can be seen in Table 4, the three alloys that stand out as having exceptional 1,366°K (2,000°F)/100 hour creep rupture specific strength are INCOLOY® 802, INCONEL® 617 and L605. The 1,366°K (2,000°F)/100 hour

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creep rupture strengths of approximately 20 MegaPascals (MPa) (3.0 kilopounds per square inch (ksi)) of these alloys are from 30 percent to over 200 percent greater than the creep rupture strengths of the rest of the solid solution strengthened alloys listed in Table 4. Approximately the same ratios also hold true for the creep rupture specific strengths.

Although INCOLOY 802 can be rolled down to sheet, it is not available commercially in the thin gauges required. Likewise, L605 is unsuitable because:

a. It has poor oxidation resistance [1,255°K (1,800°F)/ 100 hour oxidation loss of 0.0889 mm (0.0035 inch)] (Reference 8), and

b. It contains 53 percent Cobalt which increases costs and lead times.

INCONEL 617 is available in the required gauges and has excellent oxidation resistance. INCONEL 617 was therefore selected as the candidate material.

4.5 INCONEL 617

INCONEL 617 is a solid-solution, Ni-Cr-Co-Mo alloy with an exceptional combination of high temperature strength [100 hour, 1,366°K (2,000°F) 0.2 percent creep strength of 10.3 MPa (1.5 ksi)] and resistance to 1,366°K (2,000°F) cyclic oxidation (References 7, 9, 10, 11, and 12). Due to its exceptional properties, it is currently used in the combustion section of gas turbines. Strengthening of the alloy during exposure to temperature originates primarily from discrete $M_{23}C_6$ precipitates. This phase was found to remain stable at temperatures up to 1,366°K (2,000°F).

INCONEL 617 has good fabricability and formability. Machining and welding are carried out using standard procedures for nickel alloys.

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5/ FABRICATION

5.1 FABRICATION OF HONEYCOMB SANDWICH COUPON TEST SPECIMENS

Specimens of INCONEL 617 were fabricated for testing in:

a. Face sheet tension
b. Creep
c. Edgewise compression
d. Flatwise tension
e. Pressure/Thermal Gradients
f. Thermal conductivity.

All honeycomb sandwich panels were fabricated 7.1 mm by 304.8 mm by 304.8 mm (0.280 inch by 12 inches by 12 inches) and subdivided into the appropriate test specimen sizes. A modified brazing/diffusion bonding process was used for joining the INCONEL 617 honeycomb panels. The process consisted of applying braze alloy (1.97B-0.02C-13.13Cr-3.4Fe-Ni Balance) approximately 40 grams per square foot to one side of each face sheet, and installing 6.35 mm (0.250 inch) cell honeycomb core between the face sheets for joining.

The layup was placed on a flat reference in a vacuum furnace where 0.14 kilograms (0.3 pounds) per square inch of tungsten pellets were added on top of the panels to provide pressure for brazing and diffusion

bonding. The furnace was then evacuated to 1 X 10^{-4} torr and heated to 1,450°K (2,150°F), held for three minutes, then cooled to 1,311°K (1,900°F) and held for one hour before cooling to 431°K (300°F) and removing from the furnace. After bonding, all honeycomb specimens were evaluated using the ultrasonic through-transmission C-scan method.

5.2 FABRICATION OF FULL SIZE PANELS FOR PRESSURE AND THERMAL CONDUCTIVITY TESTS

INCONEL 617 subassemblies and titanium subassemblies were fabricated separately and then joined in a third assembly process.

5.2.1 FABRICATING THE INCONEL 617 SUBASSEMBLY -- The 0.13 mm by 313.30 mm by 313.30 mm (0.005-inch by 12.334-inch by 12.334-inch) skins were square sheared. The honeycomb core 6.35 mm (0.25 inch) cell by 0.08 mm (0.002 inch) thick foil by 304.8 mm by 304.8 mm by 101.6 mm (12 inches by 12 inches by 4 inches) was fabricated using a Rohr Coremaster machine. The 101.6 mm (4-inch) log was subdivided into 304.8 mm by 304.8 mm by 7.11 mm (12-inch by 12-inch by 0.280-inch) pieces using an electric discharge saw and a conventional mill and belt sander.

The side closures were formed on the 195-255 form tool as shown in Figure 5 and then hand trimmed. Since INCONEL 617 is relatively easy to form at room temperature, the form tool was made of 6061 aluminum. This form tool was machined using the numerical control machining process and then hand sanded to a smooth finish. The parts were formed in an ASEA hydropress. The side closures were formed in two stages. In the first stage, the corrugations were formed in the 195-256-9, -11, -13, and -15 side closures. (See Figure 1B for part numbers.) In the final stage, one insert was removed from each end of the form tool and one insert was added to each side of the form tool for forming the end flanges on the -13 and -15 side closures. Figure 6 shows the finished form tool and tool proof parts.

All parts were process cleaned in a pickling solution of nitric/ hydrofluoric acid before assembly. The parts were assembled with braze

alloy (1.97B-.020C-13.13CR-3.45Fe-Ni Balance) applied at all interfaces as shown in Figure 7. All components were resistance spot tack welded together at each joint. This made the assembly shown in Figure 8 self supporting for brazing/diffusion bonding. Brazing/diffusion bonding was accomplished in a vacuum furnace at a pressure of 1 X 10^{-4} torr and temperatures of 1,450°K (2,150°F) for three minutes, then cooled to 1,311°K (1,900°F) and held for one hour. After bonding, all honeycomb-core-to-skin joints were evaluated using the ultrasonic through-transmission C-scan method.

5.2.2 FABRICATING THE Ti-6Al-4V SUBASSEMBLY -- The Ti-6Al-4V skins were designed with flanges on two sides of each skin which close out the sides of the Ti-6Al-4V subassembly. Due to this configuration and the thin gage 0.15 mm (0.006 inch) material, a superplastic forming process was selected. The superplastic forming tool shown in Figure 9 was designed to form the outer and inner skins simultaneously. Forming was accomplished in a vacuum furnace where a protective environment could be provided while forming the thin gage titanium.

C1020 steel was selected as the tooling material based on the coefficient of thermal expansion and the small number, approximately 25 each, of parts required for this program. Figure 9 shows tool proof parts being removed from the tool.

The honeycomb core was fabricated in a log of 304.8 mm by 304.8 mm by 101.6 mm (12 inches by 12 inches by 4 inches) by 4.7 mm (0.18 inch) cell size by 0.05 mm (0.002 inch) foil gage, using the Rohr Coremaster machine. The core log was then subdivided into 4.3 mm (0.17 inch) thick pieces. The core was plated for LID bonding using a Rohr proprietary process.

Final cleaning was accomplished by immersion in a vapor degreaser. LID bonding was accomplished in a vacuum furnace that was evacuated to 1 X 10^{-5} torr. The part was heated to 1,213°K (1,725°F) and held for a period of time while LID material was being diffused into base material

to make the joints. After bonding, all honeycomb core to skin joints were evaluated using the ultrasonic C-scan method. Figures 10 and 11 show the completed titanium subassembly.

5.2.3 JOINING THE SUBASSEMBLIES -- The flanges of both subassemblies were prepared for LID bonding of the bi-metal joint using a Rohr proprietary process. After preparation for LID bonding, the INCONEL 617 subassembly was filled with 12.7 mm (0.5 inch) of precut DYNAFLEX and 35.3 mm (1.39 inch) of precut Q-FIBER FELT, as shown in Figures 12 and 13. After the DYNAFLEX and Q-FIBER FELT had been installed, the titanium subassembly shown in Figure 10 was installed over the Q-FIBER FELT. The flanged areas of both subassemblies were then resistance spot tack welded to each other for LID bonding. Since the subassemblies were resistance spot tack welded to each other, the assembly was somewhat self-fixturing. Only a flat reference surface was required to support the panel for LID bonding. Figure 14 shows the assembly being laid up for LID bonding the bi-metal joint. Figures 15 and 16 show a completed bi-metal panel with bayonet/clip attachments.

The 59.7 mm by 304.8 mm by 304.8 mm (2.35-inch by 12-inch by 12-inch) panel with clips and tongues weighed 0.926 kilograms (2.04 pounds). The same size panel with only through-panel fasteners weighed 0.898 kilograms (1.98 pounds). All panels were checked dimensionally and visually for defects.

The 195-254 through-panel fastener (Figure 3) is fabricated as a braze/diffusion bonded assembly. The base, flange and housing are fabricated using a standard production type blank die. The threaded insert and cap are machined using a hand screw machine (turret lathe). The parts are cleaned for brazing using a degrease solution. These parts are then assembled and resistance spot tack welded into position. Braze alloy (1.97B-0.02C-13.13Cr-3.4Fe) is applied at each joint and the assembly is placed in a vacuum furnace with the flange side down for braze/diffusion bonding at 1,450°K (2,150°F). Only a visual inspection is required to determine quality.

5.2.4 FABRICATION OF PANEL ARRAYS -- A twenty-panel array, a two-panel array, and three separate panels were fabricated and delivered to NASA Langley Research Center for further testing.

5.2.4.1 Twenty-Panel Array -- The twenty-panel array was designed to fit an existing 1078.5 mm by 1523.0 mm (42.46-inch by 59.96-inch) opening in the test apparatus for the 8-foot High Temperature Structures Tunnel. The basic panel size is 304.8 mm by 304.8 mm (12.0 inches by 12.0 inches). Therefore, three panels of 284.2 mm by 304.8 mm (11.19 inches by 12.0 inches), one panel of 284.2 mm by 149.4 mm (11.19 inches by 5.88 inches) and four panels of 304.8 mm by 149.4 mm (12.0 inches by 5.88 inches) in addition to twelve basic panels were required to fill the test fixture. An individual panel is shown in Figure 16 and the twenty-panel array is shown in Figure 17.

The panel joints were aligned with the flow so that gas flow in the joints could be studied during tunnel tests. The array of panels were attached to a 4.8 mm (0.190 inch) thick plate, shown in Figure 18, which represents the mass of the shuttle fuselage structure at the design location, body point 1300.

Panel fabrication was accomplished using the process parameters described in Section 6. The panels were processed six at a time, as shown in Figure 19. The quantity was governed only by the available furnace size.

All honeycomb subassemblies were evaluated using the ultrasonic through-transmission C-scan method. All subassemblies and final assemblies were checked dimensionally for conformance to the drawing. The final assemblies, such as that shown in Figure 15, were pressure checked in an unrestrained position to 14 KPa (2 psi) internal pressure.

To pressure check the panels a Meriam manometer using Meriam 295 Red Fluid (2.95 specific gravity), shown in Figure 20, was used. A regulator

in the airline was used to prevent the panel from being over-pressurized when the flexible tygon line was placed over the vent hole in the lower panel.

Evaluation showed some panels to have intracell dimpling of the face sheets. This was not considered to be a structural problem since some of the specimens tested and reported in Section 7 had intracell dimpling and had acceptable test results.

5.2.5 INSTRUMENTATION -- The 20-panel array and the 2-panel array were instrumented with Type K thermocouples. INCONEL sheath was used where the temperature was expected to be above 1,255°K (1,800°F) and 30 gage fiberglass sheath couples were used in areas where the temperature was expected to be below 1,255°K (1,800°F). Five INCONEL sheath type couples were installed inside an INCONEL 617 subassembly before final assembly. This panel was installed at the 2-C location in the 20-panel array. Figures 21 and 22 show the thermocouple layout for both arrays.

5.2.6 INSTALLATION -- The panels having clips and tongues as means of attachment were somewhat more difficult to install on the aluminum plate than the panels having through-panel fasteners. This was due to having to compress the NOMEX felt, which was coated with RTV rubber, while sliding the tongue into the clips. The 20-panel array had pressure probe connections installed in seven places, as shown in Figure 21. The pressure probes were located to detect pressure buildup between the aluminum plate and the bottom side of the panels during tunnel tests.

Three additional panels were mounted on individual 4.8 mm (0.19 inch) thick plates. These plates each had NOMEX felt installed between the panel and the plate, but had no instrumentation. These panels were interchangeable with other panels in the 20-panel array.

6/ THERMAL PERFORMANCE

The procedure followed for the thermal analysis was:

a. Entry conditions were used for shuttle body point 1300 and a transient thermal analysis was run to size insulation thickness, (i.e., design of overall tile thickness).

b. Steady-state temperatures were measured across manufactured tiles. Measured hot and cold face surface temperatures were used and a steady-state thermal analysis was performed to predict temperatures and effective conductivity, and to correlate them with test values.

6.1 TRANSIENT ANALYSIS TO DETERMINE PANEL THICKNESS

Figure 23 represents the thermal math model used in the MITAS lumped parameter thermal analysis computer program (Reference 13) to size the insulation thickness of the tile. The temperature and pressure histories shown in Tables 2 and 3 for shuttle body point 1300, trajectory 14414.1C were supplied by Langley Research Center as a starting point for the thermal analysis. Thermophysical properties of the INCONEL 617 honeycomb, DYNAFLEX®, Q-FIBER FELT®, titanium honeycomb, and aluminum used in the analysis are provided in Tables 5-8, respectively.

® DYNAFLEX is a registered trademark of Johns-Manville Corp., Denver, Colorado.

Q-FIBER FELT is a registered trademark of Johns-Manville Corp., Denver, Colorado.

Because the external pressure varies with time, the insulation thermal conductivity was allowed to vary with pressure in addition to the usual temperature variation. The resulting maximum temperature of the aluminum plate was determined from a transient analysis for various cases, with a different, arbitrarily selected, thickness of insulation. To ensure that stored energy at the end of entry does not continue to heat the aluminum structure, the given temperature and pressure histories were extended to 2,000 seconds. Because the Q-FIBER FELT has a temperature limit of 1,255°K (1,800°F), care was taken in the analysis to ensure that this limit would not be exceeded.

During the early computer runs, the temperature at point 28 of the math model was monitored and evaluated as a function of DYNAFLEX and Q-FIBER FELT thicknesses. From this it was determined that a 12.7 mm (0.5 inch) thickness of DYNAFLEX would keep the insulation interface below 1,255°K (1,800°F). The remaining analyses, therefore, had the DYNAFLEX thickness fixed at 0.5 inch, but used various Q-FIBER FELT thicknesses.

Typical results of the transient analysis are shown in Figure 23, where temperature responses are shown for the case where the total thickness of the tile is 55.9 mm (2.35 inches). For this case the insulation interface was 1,117°K (1,550°F) and the maximum temperatures of the aluminum was 439°K (330°F). The maximum temperature of the aluminum for three insulation thicknesses is shown in Figure 24. Extrapolation of this data to 454°K (350°F) establishes a required thickness of 58.4 mm (2.3 inches). Because the TPS thickness was selected at an early stage in the program, the tile design thickness of 59.7 mm (2.35 inches) was not changed.

6.2 STEADY-STATE ANALYTICAL PREDICTION AND CORRELATION OF TEMPERATURE DISTRIBUTION AND EFFECTIVE CONDUCTIVITY WITH THE TEST RESULTS FOR THE BI-METAL THERMAL PROTECTION SYSTEM

6.2.1 TESTS -- Thermal conductivity tests were performed using a modified guarded hot plate shown in Figures 25 and 26. The hot plate has quartz lamps that are divided into three independent heating zones;

control, mid, and edge. Separate automatic controls are used to minimize the temperature gradient between the central test section and the mid guard heater. The edge guard heater, in turn, minimizes the temperature gradient between the mid test section and the edge. In this way, the apparatus is a double guarded system. This minimizes any radial heat flow away from the central test section. Min-K, having a known thermal conductivity, was used as a test standard to calibrate the test apparatus and run thermal conductivity tests.

The test panels are shown in Figures 27 and 28. The test setup shown in Figure 29 was used for checking thermal conductivity of the superalloy panel. The test panel was placed on top of a honeycomb panel and the known thermal conductivity instrumented Min-K was placed on top of the test panel. The honeycomb panel was used as the "Hot Plate" to provide a more uniform heating of the test specimen. The honeycomb panel was instrumented with thermocouples, the outputs of which were fed into the automatic control circuit in order to maintain the test temperature. The test panel was instrumented with thermocouples that were welded onto both sides of the panel surface at the center, midway between the center and edge, and at edge locations. Because of the physical nature of the Min-K, thermocouples could not be attached directly to its surface. Therefore, thermocouples were put on small INCONEL rectangular tabs which were insulated from the metal surfaces of the test panel and aluminum plate, but were forced onto the Min-K surfaces by the weight of the test setup. Thermocouple plan-form locations on the Min-K were the same as for the test panel.

6.2.2 ANALYSES -- Measured boundary temperatures obtained from the steady-state thermal conductivity tests were used as boundary conditions in thermal analyses to predict the temperature distribution of a 304.8 mm by 304.8 mm (12- inch by 12-inch) bi-metal TPS tile.

Figure 30 represents the thermal math model used for the analysis. The model differs from the transient model in that it includes a cold face boundary, Min K insulation, no primary structure, and no gap radiation.

The thermophysical properties used for the analysis are presented in Tables 5 through 9. Since the test was conducted at sea level pressures, only the 2,116 pounds per square foot (1 atmosphere) were used.

Results

Steady-state computer runs were performed using, as boundary temperatures, the measured temperatures of the hot face (node 1) and cold face (node 17). The analytical temperature of node 13 (cold side of the titanium honeycomb) was compared with the measured temperature. Two sets of computer runs were performed, one without sidewall to predict the temperature in the center of the tile, and another with a sidewall to predict the temperature adjacent to the sidewall. The transient model and the original steady state model had the sidewall conducting directly from node 1 to node 13. It was necessary to change the model only for one steady state solution. That is, measurements along a line directed from hot face to cold face and through the tile center could be correlated without sidewall conduction in the thermal model. Measurements near the sidewall needed the addition of sidewall conduction retained in the thermal model to obtain a close correlation. Table 10 presents the boundary temperatures used and a comparison of the predicted and measured temperatures for node 13.

Figure 31 presents the percent error of the predicted temperatures versus measured temperatures. For the area above the zero percent line, the analytical model predicts higher temperatures and is, therefore, conservative. Based on that error, a 452°K (350°F) analytical predicted temperature for the cold face of the titanium honeycomb will have an actual temperature of 447°K (344.8°F). Based on the sidewall error

curve, the cold face of the titaninum honeycomb will be 422°K (335.7°F). In the actual case, the aluminum structure diffuses the temperature so that actual temperature will be somewhere between the two.

Figure 32 presents the effective thermal conductivities (calculated from temperatures obtained from the test data and from temperatures obtained from the thermal math model) as a function of mean temperature at the center of the panel.

The center measured temperature differences (ΔT) and thickness (ℓ) of the test specimen (TS) and Min-K (MK) were used to calculate the effective thermal conductivity (k) as follows:

Since

$$Q/A = \frac{k_{TS}}{\ell_{TS}} \Delta T_{TS} = \frac{k_{MK}}{\ell_{MK}} \Delta T_{MK}$$

Then

$$k_{TS} = \frac{\ell_{TS}}{\ell_{MK}} \frac{\Delta T_{MK}}{\Delta T_{TS}} k_{MK}$$

The conductivities k_{MK} and k_{TS} are evaluated at the arithmetic mean temperatures,

$$T_{MK} = T_{MK}(\text{HOT SIDE}) - \frac{\Delta T_{MK}}{2}$$

and

$$T_{TS} = T_{TS}(\text{HOT SIDE}) - \frac{\Delta T_{TS}}{2}$$

It is noted there is very little difference between analytical and measured K's thereby indicating that the analytical model is very good.

The through panel fastener, Figure 3, was designed for low heat transfer by ensuring that the three modes of heat transfer were minimized. To block radiation and restrict air convection, fibrous insulation, DYNAFLEX®, was placed within the cavity of the fastener. In that way DYNAFLEX's very low thermal conductivity is substituted for those two terms. Therefore, the heat transfer becomes primarily a conduction problem. Metal conduction was minimized by keeping the cross-sectional area (the conducting area) normal to the panel axis small, i.e., fastener conduction area/panel total area is a small value. The maximum number of fasteners per panel is four. So, for a panel that is 304.8 mm by 304.88 mm, the conduction area ratio is four times each fastener conduction area/(304.8 by 304.8). This is (4π) (14.478) (0.127)/(304.8 by 304.8) = 0.00025. The effective thermal conductivity of a panel with fasteners, k_{TWP}, may be approximated by $k_{TWP} = 0.00025\ k_p + (1 - 0.00025)k_T$ where k_p is fastener material conductivity and k_T is panel thermal conductivity.

The CERACHROME® contribution is not included because its conductivity is nearly the same as k_T.

This equation may be rewritten as

$$(k_{TWP}/k_T) = 0.00025\ (k_p/k_T) + 1 - 0.00025$$

At 900F (482.2C), k_p = 11.92 Btu/hr ft f(20.6228 w/mk)
and from Figure 32 k_T = 0.07 Btu/hr ft F (0.1211 w/mk)

Thus

$$(k_{TWP}/k_T) = 0.00025\ (11.92/0.07) + 1 - 0.00025$$

$$(k_{TWP}/k_T) = 1.04$$

i.e., a maximum increase of 4.0 percent would be expected for the panels' k.

Based on these test results, the thermal conductivities used in the thermal math model are considered acceptable for future thermal analyses.

7/ STRUCTURAL PERFORMANCE

7.1 GENERAL

The purpose of the structural evaluation program was twofold:

a. To provide basic mechanical properties of the brazed INCONEL 617 sandwich.

b. To predict and verify the structural performance of the panel design and manufacturing processes.

7.2 MECHANICAL PROPERTIES OF INCONEL 617 HONEYCOMB SANDWICH

The basic mechanical property testing was performed on coupon size specimens while the structural and thermal performance verification was performed on a full size panel. The full size panel tests verify that the panel is able to withstand a realistic simultaneous pressure load and temperature environment. The coupon test quantifies the strength properties of the material system and verifies that the panel met all of the design requirements. An outline of the test program with the number of specimens involved is provided in Table 11.

During the coupon testing, face sheets and sandwich structures with various gages (including the final design configuration) were tested. Specimens were ultrasonically C-scanned prior to testing. Specimen locations were marked on the C-scans and the panels. Photographs were taken of the panels for a permanent record of their location. Each specimen was identified by a number/letter combination that related it to the panel from which it came and to the type of test that was performed on it.

The remainder of this section provides details of all of the testing. These details include a description of:

a. Test specimen configuration
b. Test apparatus and procedures
c. Test results.

7.2.1 FACE SHEET TENSION TESTS -- Tests were conducted to determine the basic mechanical properties of INCONEL 617 foil material as received and after being subjected to various conditions. These conditions included:

a. Processed/brazed to honeycomb core
b. Pretest exposure to 1,366°K (2,000°F) for either 5 or 25 hours.

Test temperatures varied from room temperature to 1,366°K (2,000°F). The following mechanical properties were determined:

a. Yield (Fty) and ultimate (Ftu) stress
b. Percentage elongation (e)
c. Modulus of elasticity (E).

The modulus of elasticity values were measured from load - deflection curves that were plotted in conjunction with a linear variable differential transformer (LVDT) and with the Instron test machine.

The specimens, except for the as-received specimens, were cut from brazed INCONEL 617 honeycomb sandwich panels. The honeycomb core was removed from the face sheets with a high speed grinder. The overall specimen size was 2 inches by 10 inches with a 1-inch wide test section. Two thicknesses were tested: 0.076 mm (0.003 inch) and 0.127 mm (0.005 inch).

The test program and results are summarized in Figure 33 and in Tables 12, 13, and 14. The groupings are by duration of pretest 1,366°K (2,000°F) exposure. These are respectively: none, 5 hours and 25 hours. The pretest thermal exposure was performed to determine the degradation of material properties over the life of a panel. It has been estimated that these panels would be exposed to 1,256° to 1,366°K (1,800° to 2,000°F) environment for approximately 300 seconds during every flight or approximately 8 hours for 100 flights. This duration was conservatively bracketed by the 5 and 25 hour exposure times and using the upper temperature value of 1,366°K (2,000°F). The atmosphere used for this exposure was sea level air -- a conservative condition since most entry heating occurs at a high altitude.

The test specimens were separated from the core prior to exposure. The effects of this pretest exposure are discussed in subsequent paragraphs and are also illustrated metallographically in Figures 34 through 36. Figure 35 shows the typical microstructure of the INCONEL 617 alloy in the solution-annealed condition. Figure 35 shows the foil after being brazed to honeycomb core and being exposed for 5 hours at 1,366°K (2,000°F). The rough upper surface is braze alloy. A very thin gray layer on the surfaces indicates an oxidation film. Dark lines and spots indicate the beginnings of intergranular oxidation. Figure 36 is the same except the exposure duration of 1,366°K (2,000°F) temperature has been increased to 25 hours. The oxidation film has increased in thickness and the intergranular oxidation is significantly greater.

Table 12 summarizes the testing on specimens that had not been subjected to pretest thermal exposure. The yield and ultimate strength values are comparable to, or slightly higher than, published data. The percent elongation of the as-received material is considerably lower (12 percent versus 31 percent) than the values on the material certification sheets that were produced by the material vendor. Subsequent investigations showed that if the test specimens are more carefully prepared (to ensure failures in the two-inch test area) and load rates are reduced to 0.51 mm (0.02 inch) per minute crosshead speed, elongation values increase from 12 percent to 34 percent.

Tables 13 and 14 summarize the testing on specimens with 5 and 25 hours of 1,366°K (2,000°F) pretest thermal exposure, respectively. These exposures have only a moderate impact on the yield strength values. However, the ultimate strength and the percent elongation values continue to decrease with the duration of pretest exposure. The reduction stabilizes at 1,366°K (2,000°F) and the number of hours of exposure does not affect these test values. Therefore, the pretest exposure durations are most critical for room temperature mechanical properties. Figures 37 and 38 display this point graphically. Percent elongation values show the same trend.

7.2.2 CREEP TESTS -- Tests were conducted to determine the long term strength of INCONEL 617 foil material when exposed to elevated temperature and sustained stress levels. The test matrix is shown in Table 15. As shown, the testing included temperatures from 1,089° to 1,366°K (1,500° to 2,000°F) and foil conditions of as-received and processed/brazed-to-honeycomb core.

The initial test specimen configuration was 6.4 mm (1/4 inch) wide by 51 mm (2 inches) long by 0.08 mm (0.003 inch) thick. This specimen proved to be adequate at the 1,089°K (1,500°F) test temperature condition; however at 1,366°K (2,000°F) it produced widely scattered results which are not reported. The reason for the scatter is believed

to be related to the small size of the test specimen and the resulting small load requirements. The specimen size was then substantially increased to 19 mm by 76 mm by 0.08 mm (3/4 inch by 3 inches by 0.003 inch) for all 1,255°K and 1,366°K (1,800°F and 2,000°F) testing. The test setup is shown schematically in Figure 39 with an overall photograph in Figure 40. Note that specimens are dead weight loaded and that creep deflections are automatically plotted as a function of time. The larger creep specimen, along with three thermocouple probes, is shown in Figure 41.

The test data is tabulated in Table 16 and is shown in the Larson-Miller plots in Figure 42. The total elevated temperature life of the structure is estimated to be 8 hours for 100 missions (See Section 7.2.1) with a maximum temperature of 1,311°K (1,900°F). For the purpose of comparing this test data with actual stress-temperature conditions, specific stress and temperature points are provided. This comparison conservatively treats the total eight hours as occurring at each temperature point examined.

7.2.3 EDGEWISE COMPRESSION TESTS

These tests were conducted to evaluate the ability of thin foil gages to carry significant compressive loads. These thin gages, when bonded into sandwich structure, do have some initial waviness. Therefore, it had been theorized that these sheets were already in a buckled condition and as such would be unable to carry any significant compressive loads. The tests completely disproved this theory because ultimate compressive stresses of considerable magnitude were measured.

The test specimens were brazed INCONEL sandwich with a square cell core that had a height of approximately 7.1 mm (0.280 inch). The specimens were 76 mm (3 inches) wide and 89 mm (3.5 inches) long in the direction of the applied load. The ends of the specimens were potted with an acrylic compound to provide local support and uniform load application. The specimens with 0.08 mm (0.003-inch) thick face sheets had considerably more initial face sheet waviness than those with 0.13 mm (0.005 inch) face sheets.

The test program and results are tabulated in Table 17. The specimens were tested in accordance with ASTM C364. The failure mode for all specimens was intracell buckling, which is to be expected for a sandwich with thin face sheets and large ratios of cell size to face sheet thickness. Figure 43 plots the test results versus analytical results. This figure shows that there is close agreement for the 0.13 mm (0.005-inch) face sheets. However, the test results for the 0.08 mm (0.003-inch) face sheets are approximately 30 to 75 percent higher than the analytical results.

The analytical results are from an intracell buckling equation (See equation C12.5.1 of Reference 18) which was developed from tests of standard sandwich specimens and almost certainly never involved these foil type gages. Therefore, the discrepancy between analytical and test results is attributable to inaccuracy in the analytical method when dealing with large ratios of cell size to face sheet thickness and large ratios of braze alloy to face sheet thickness. Consequently, the analysis conservatively underestimated the specimen load carrying capability.

7.2.4 FLATWISE TENSION TESTS

Flatwise tension testing is a standard method of assessing the process procedures of the bonding operation. The results are not directly used in the stress analysis but they do provide a means of comparing the strength of various bonded joints. The data presented includes room and elevated temperature data on both environmentally exposed and unexposed specimens. The environmental exposure was in a 1,366°K (2,000°F) air furnace for either 5 or 25 hours. The test setup for room temperature testing is shown in Figure 44. The test setup for elevated temperature testing is shown in Figure 45.

The test plan is shown in Tables 18A and 18B. As shown, some of the E panel specimens received a pretest thermal exposure. As in the case of the face sheet tension tests, this exposure was performed to determine

the degradation of material properties over the life of a panel. It has been estimated that these panels would be exposed to 1,256° to 1,366°K (1,800° to 2,000°F) environment for approximately 300 seconds during every flight or a total of approximately 8 hours for the 100-flight design life. This duration was conservatively bracketed by the 5 and 25 hour exposure times at 2000°F. There were several conservative procedures used during this pretest exposure. They include:

a. A 1,366°K (2,000°F) exposure (the upper temperature limit)
b. A test atmosphere of sea level air (actual exposure will be at elevations where there is rarefied atmosphere)
c. Exposing the separate 76 mm by 76 mm (3-inch by 3-inch) specimens rather than an entire panel with edge closures which would protect the interior part of the panel.

Another feature of the test program was room temperature and elevated temperature testing. The room temperature specimens had loading blocks adhesively bonded to them. The elevated temperature specimens had the loading blocks brazed to them using 1.97B-0.02C -13.13Cr -3.4 Fe braze alloy at 2175°F. This process did not interfere with the sandwich brazed joints.

The first panels that were fabricated for these tests were designated AFT and GFT. As defined in Tables 18A and 18B, they had 0.08 mm (0.003 inch) face sheets and 4.6 mm (0.1875 inch) cell core. C-scans of these panels showed varying degrees of bond quality. In order to correlate C-scan readings with joint strength, the panels were cut into specimens and tested. Test specimen numbers and results were recorded on the C-scans. As a result, a high degree of correlation was identified between the C-scans and the flatwise tension strengths. Those specimens that showed low quality bonds in the C-scans had considerably less strength (on an average of 1/3 to 1/2) than those without disbonds. The disbonds in these panels were attributed to early development problems in the manufacturing process. The test results for these panels are not

included in this report. The E panel, which was fabricated subsequent to the A and G panels, had ideal C-scans. The configuration of the E panel is identical to the production panel design (0.005 each face sheets and 0.25 inch cell core). Only the results of E panel flatwise tension tests are reported here.

The room temperature test results for the E panel specimens are tabulated in Table 19 and plotted graphically in Figure 46. The reduction in strength after exposure to 1,366°K (2,000°F) is attributed to oxidation of the core and not to oxidation of the braze joint. This conclusion is supported by the failure modes and photomicrographs of the joints. In fact, some of the 25 hour exposed core had failed locally prior to loading due to the exposure. The failure mode for the unexposed specimens was 100 percent in the brazed joint while the exposed specimens had large areas of core failure. Figures 47 through 49 show the brazed joint of a core cell wall and a face sheet after various amounts of 1,366°K (2,000°F) exposure. It is evident that the cell wall is being attacked much more severely than the braze joint. It should be noted that even the core in the center of the specimens was oxidized. The air passageways are through the cell nodes which are spotwelded together.

The elevated temperature results of testing specimens from the E panel require a special explanation. The low results shown in Table 19 are the result of extenuating circumstances. After 25 hours at 1,366°K (2,000°F), the 76.2 mm by 76.2 mm (3-inch by 3-inch) specimens were severely warped as well as oxidized. This warpage could have been alleviated by subjecting a large panel to the exposure instead of the small 76.2 mm by 76.2 mm (3-inch by 3-inch) specimens. For room temperature tests, this warpage does not cause any great problems because additional adhesive can be added to fill gaps between the loading blocks and face sheet. However, the elevated temperature specimens require that loading blocks be attached by brazing alloy, which can not fill large gaps like the adhesive. Consequently, during the test, there was uneven loading and local separation of the face sheets from the loading blocks. These

test conditions and results must be considered unrealistic to any actual service operation.

As stated previously, flatwise tension results by themselves are not a normal part of the stress analysis. However, they provide a means to evaluate the effects of other parameters on joint integrity. In this test it has been shown that a 1,366°K (2,000°F) exposure in an oxygen rich atmosphere over a period of time has a significantly deleterious effect on the sandwich structure. However, the conservative nature of the testing has measured reductions that far exceed those which would result from the flight design life.

7.3 STRUCTURAL ANALYSIS OF FULL-SIZE PANEL

7.3.1 FINITE ELEMENT MODEL -- A finite element model of the entire panel was constructed in order to determine the internal stresses and external deflections for the design conditions discussed in Section 3.0. The model, shown in Figure 50, has approximately 390 nodes. The coded model input sample is shown in the appendix. The computer program selected for the analysis was NASTRAN. The selection was based on the fact that this program has industry wide acceptance and use, and Rohr has extensive experience with it. The upper INCONEL sandwich and the lower titanium sandwich panels were modeled using one inch by one inch panel elements which are defined as CQUAD4. CQUAD4 panel elements are special plate members that represent sandwich structure. The sidewalls were modeled as a combination of two different elements. These elements are CSHEAR, to represent the sidewalls capability to react shear loads, and pinned CBAR members, to represent the beam-column load capability of the corrugated flutes. The clip and bayonet attach fittings are modeled as rod members as shown in Section A-A and B-B in Figure 50. Rods were selected so there would not be any bending capability in these supports. In addition, the rods were given an axial stiffness which was determined from a full panel pull test. Subsequently, the pressure and thermal gradients described in Section 3.0 were applied to the model. The stress levels are discussed below and the deflection values are discussed in Section 7.4 of this report.

7.3.2 STATIC STRESS ANALYSIS -- The calculated stresses, for the two ascent conditions and the one descent condition, are shown on Figures 51-A through 51-F. These stresses are superimposed on finite element models in order to provide a representation of the stress distributions within the panels. The panels have two center lines of symmetry, therefore only a quarter of the panel is required to define the internal stress distributions. The stresses shown on the INCONEL and titanium honeycomb are principal major or minor stresses with (+) representing tension and (-) compression. The stresses shown on the sidewalls in parentheses are shear stresses and the other sidewall stresses are axial loads in the bars representing the corrugations.

The all positive margins of safety for the critical stresses from these conditions are tabulated in Tables 21A and 21B. Included in these tables are allowables for the INCONEL and titanium honeycomb, INCONEL sidewalls and the titanium bayonet attach fittings. The critical failure mode for the honeycomb structure is intracell buckling. The allowable curve for the INCONEL is shown in Figure 52. It is based on room temperature test data from edgewise compression tests (Table 17), and temperature reduction factors based on modulus of elasticity (E). The E values were generated during the mechanical property testing and are averages of specimens pretest exposed to 5 hours of 2000°F and those exposed to 25 hours of 2000°F (see Figure 38). The titanium honeycomb allowable, shown in Figure 53, is based on equations in Reference 17. The INCONEL sidewall, which was found not to be stability critical, has allowables based on F_{ty} shown in Figure 37 . The value used is an average between the curves for 5-hour and 25-hour pretest exposure of 2000°F. The titanium bayonet fittings have allowables based on MIL-HDBK-5D values for Ti-6Al-4V.

In conclusion, the successful structural panel testing verifies the analysis and the integrity of the panel.

7.4 THERMAL/PRESSURE TESTS ON FULL-SIZE PANEL

7.4.1 GENERAL -- In order to verify the structural integrity of a total panel assembly, a series of thermal and pressure gradient tests were conducted. A panel assembly, which was fabricated to Rohr Engineering Drawing 195-256, was installed in a test fixture in a manner which accurately simulated installation to a vehicle surface. The test panel, which was instrumented with thermocouples and dial indicators, is shown in Figure 28.

7.4.2 TEST FIXTURE AND INSTRUMENTATION - The test fixture (Rohr Drawing 501-560) is shown schematically in Figure 54. Photographs of the test fixture and instrumentation are shown in Figures 55 through 59. In the schematic, starting at the bottom, there are dial indicators with ceramic dowels which penetrate through the quartz lamps. The quartz lamp bank array is shown in Figure 56. The ceramic dowels, shown protruding through the lamps, must penetrate a water chamber which circulates water to cool and protect the aluminum support plate. Surrounding the lamp bank (not shown in Figure 54 but shown in Figure 55) is a rectangular, gold-plated reflecting shield which keeps the heat in and on the panel.

A completely independent and separate assembly is suspended above the lamp assembly. This assembly contains:

a. The test panel
b. Mounting clips
c. Seals
d. A pressure chamber to load the panel.

The test panel has its exterior surface exposed directly to the lamp array. The panel is clipped into the base of the pressure chamber. Figure 57 shows this chamber in an inverted position and without the cover plate. Note that the clips and bayonet fittings for the normal mating structure are included.

Also shown in this figure and in the schematic of Figure 54 are two different seals. The design and function of these silicone seals is very important. The seal on the outer perimeter simulates the NOMEX® pad that would be installed on the shuttle vehicle. This pad is compressed during panel installation and provides a tight fit for the panel. It also reacts crushing pressure loads that push the panel against the vehicle. The test seal is purposely not bonded to the panel so that it will not inadvertently react blowoff pressure loads that pull the panel away from the vehicle.

The inner seal is referred to as the flap seal. It provides the seal to the pressure chamber. As such it must be bonded to the panel but also must not react any blowoff loads. This is possible because of the seal design. The seal is L-shaped and, since it is made from silicone rubber, does not have any bending stiffness. Consequently, the seal is incapable of reacting load and therefore all loads go through the clips as they should. Figures 58 and 59 show views of this seal as it attaches to the bottom of the panel. Also note the holes in the panel. The holes assure that all pressure gradients will be across the outer INCONEL sandwich structure. These holes are not part of the panel design but are incorporated in the test to accommodate rapid pressure changes that could take place during the test but not during actual flight conditions. The final part of the fixture is a cover plate which is bolted on. A vacuum pump provides crush pressure and an external air supply provides blowoff pressure. Both are monitored by a pressure gage.

Figure 55 shows, on the far left, a Thermac Controller (Research Incorporated) which regulates power to the quartz lamps. To the right of this is a Fluke Data Logger which records the temperatures from the thermocouples.

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7.4.3 TEST PROGRAM AND RESULTS -- The testing was performed according to the six conditions outlined in Table 22. The intent of the program was to cover as many possible design conditions as practical and to do so in a conservative manner. Note that the critical design conditions described in Section 3.0 are met or exceeded by these test conditions. The ascent design conditions listed in Table 1 is exceeded by test conditions V and VI and the descent design condition is approximated by test Condition IV. At the time of the test, the precise temperature gradient had not been calculated. In this test program, the design ultimate burst and crush pressures were initially applied at room temperature. Subsequently the panel was subjected to the maximum 1,366°K/477°K (2,000°F/400°F) temperature gradient without pressure loads. Next, the design ultimate burst pressure load was applied in combination with a conservative temperature gradient (a higher temperature gradient than that expected in combination with pressure) of 812°K/311°K (1,000°F/100°F). After successfully passing this severe condition, the loading was increased to determine the margin of safety. At 25 KPa (3.6 psi) an air leak occurred at two of the corners of the panel and the testing was terminated. Other than these small holes at the two corners there was no discernible damage to the panel.

The panel was repaired by placing a 0.08 mm (0.003 inch) thick piece of INCONEL 617 foil over the holes. Resistance spot welds were then made between the foil and the panel to close the holes. The panel was re-installed in the test fixture, heated to the 812°K (1,000°F)/311°K (100°F) temperature gradient, and pressurized to 25 KPa (3.6 psi) at which time a pressure drop was again noted. The panel was removed and evaluated. A failure in the INCONEL 617 side closures at the titanium 6Al-4V intersection as shown in Figures 60 and 61 was noted. Tack welds used to stabilize the panel during LID bonding held when the bonded area between tack welds separated causing small tears in the side wall. Since the failure was primarily in the base material, no other attempt was made to repair the panel.

The heat-up rates on the test panel were controlled and were those calculated for an entry condition for body point 1300. These temperatures were monitored during heat-up and during load application. Table 23 shows the temperatures for various burst pressure loads. The results verify the consistent and uniform temperature gradients that were established throughout the panel.

Figure 62 plots the deflections at the center of the top surface of the panel versus applied pressure loads. For the severe test condition of 14 KPa (2 psi) burst pressure plus 811°K/311°K (1,000°F/100°F) temperature gradient, the deflection at the center of the panel was 4.0 mm (0.156 inch): 1.5 mm (0.060 inch) due to thermal and 2.4 mm (0.096 inch) due to pressure. In order to relate this to panel bow, Figure 63 was plotted. The plot shows deflection values at all 4 corners of the panel, the middle of one side and the center of the panel for the severe condition. The plotted deflections are those due to pressure only and the thermal deflections are presented in tabular form. In order to calculate maximum panel bow (an aerodynamics performance concern), the value of the corner with the smallest deflection is subtracted from the panel center deflection. For the 14 KPa (2 psi) plus 811°K/311°K (1,000°F/100°F) condition, corner number one had the smallest deflection. This value was 1.3 mm (0.051 inch): 0.3 mm (0.011 inch) due to thermal and 1.0 mm (0.040 inch) due to pressure. Therefore, the maximum panel bow for the ultimate design condition was 2.7 mm (0.105 inch). The nonlinearity in the deflection curves above the 14 KPa (2 psi) load is attributed to bending in the clips.

Table 20 presents a comparison of deflections obtained from the test versus those calculated by the NASTRAN finite element model described in Section 7.3. As shown, the analytical procedure underestimated the test results except for the 2 psi room temperature blowoff condition. These higher analytical results are surmised to be from an under prediction of the stiffness of the bayonet support fittings.

In conclusion, the panel design and manufacturing processes were demonstrated by full scale tests to be completely adequate to withstand the design criteria defined in Table 1. Consideration should be given as to whether protective coatings are necessary for the exterior of these panels in order to reduce the oxidation effects of elevated temperatures.

8/ CONCLUSIONS

A metallic reusable Thermal Protection System (TPS) panel with the potential for withstanding 1,366°K (2,000°F) was designed to protect areas of space reentry vehicles where the temperature does not exceed 1,311°K (1,900°F) and the pressure load is no greater than 14 KPa (2 PSI).

Test panels were fabricated using existing production facilities and processes. It was demonstrated that the panels can be mass produced by processing large quantities of parts simultaneously. One array of twenty panels and five extra panels were fabricated and delivered to NASA Langley Research Center for additional Testing. A TPS panel was designed using the thermal requirements for Space Shuttle body point 1300 as representative design criteria. Thermal and structural analyses were performed. Component specimens and full size panels were fabricated and tested to verify the design. Comparison of analytical and test data substantiate the analysis methods and verify the thermal and structural performance of the panels.

9/ REFERENCES

1. Blair, Winford; Meaney, John E., Jr.; and Rosenthal, Herman A.: Design and Fabrication of Titanium Multi-Wall Thermal Protection System (TPS) Test Panels. NASA CR-159241, February 1980.

2. Blair, W.; Meaney, J. E., Jr.; and Rosenthal, H. A.: Fabrication of Titanium Multi-Wall Thermal Protection System (TPS) Test Panel Arrays. NASA CR-159383, December 1980.

3. Mearey, J. E.: Extensional, Bending and Twisting Stiffness of Titanium Multi-Wall Thermal Protection System (TPS). NASA CR-165866, April 1982.

4. Blair, W.: Fabrication of Titanium Multi-Wall Thermal Protection System (TPS) Curved Panel. NASA CR-165754, August 1981.

5. Shideler, J. L.; Kelly, H. N.; Avery, D. E.; Blosser, M. L.; and Adelman, H. M.: Multiwall TPS - An Emerging Concept. J. of Spacecraft and Rockets, Vol. 19, No. 4, July-August 1982.

6 Jackson, L. R; and Dixon, S. C.: A Design Assessment of Multiwall, Metallic Stand-off, and RSI Reusable Thermal Protection Systems Including Space Shuttle Application. NASA TM-81780, April 1980.

7. Hays, D.. "An Assessment of Alternate Thermal Protection Systems for the Space Shuttle Orbiter. NASA CR-165790, February 1982.

8. Proceedings, National SAMPE Technical Conference P189 - "Space Shuttle Materials," October 1971, Vol. 3.

9. D. J. Tillack, INCONEL Alloy 617, Data for Use in the Design of Gas Turbine Components, Huntington Alloys, July 1979.

10. Technical Data Sheet, INCONEL Alloy 617, Huntington Alloys, 1979.

11. Bassford, T. H.; and Schill, T. V.: "A Review of INCONEL Alloy 617 and its Properties after Long-Time Exposure to Intermediate Temperatures," ASME MPC-10 presented at The Third National Congress on Pressure Vessels and Piping - San Francisco, CA, June 24-29, 1979.

12. Mankins, W. L.; Hosier, J. C.; and Bassford, T. H.; "Microstructure and Phase Stability of INCONEL Alloy 617," Metallurgical Transactions, Col. 5 (December 1974) pp 2579-2589.

13. "MITAS (Martin Marietta Interactive Thermal Analysis System) "MITAS-II-FTN Version, Users Manual, Martin Marietta, March 22, 1978.

14. Hosier, J. C.; and Tillack, D. J.; "INCONEL Alloy 617 - A New High-Temperature Alloy," Metals Engineering Quarterly, August 1972.

15. Elam, B. F.: "Heat Transfer in Honeycomb-Core Sandwich Panels," ASME 65-HT-13, 1965.

16. Glaser, P. E.; Wechsler, A. E.; Simon, I.; and Berkowitz, J.: "Investigation of Materials for Vacuum Insulation up to 4000°F," ASD-TDR-62-88, Directorate of Materials and Processes, Aeronautical Systems Division, Wright-Patterson A.F.B., Ohio, January 1962.

17. Wechsler, A. E.; and Glaser, P. E.; "Investigation of Thermal Properties of High Temperature Insulation Materials," ASD-TDR-63-574, Air Force Materials Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson A.F.B., Ohio, July 1963.

18. Bruhn, E. F.: "Analyses and Design of Flight Vehicle Structures", TriState Offset Company, Cincinnati, Ohio, c.1965.

Table 1. Design Criteria - Body Point 1300

LOAD CONDITION	OUTER PANEL			INNER PANEL		
	ΔP (PSI) ULTIMATE	T OUTER SURFACE °F	ΔT °F	ΔP (PSI) ULTIMATE	T INSIDE SURFACE °F	ΔT °F
Ascent	± 2.0[a]	650[b]	50[c]	0.0[d]	100[c]	0[c]
Descent	0.0[e]	1900[f]	31[f]	0.0[c]	208[f]	24[f]

a) This value is a contractual requirement and can be either a blowoff or crush pressure.

b) Reference 7, Pages 2-9.

c) Assumes same heating rates for ascent as descent. See Figure 4.

d) Panel has vent holes through inner sandwich layer.

e) Reference 7 reports that descent shock pressures occur only after panel has cooled down to nearly ambient temperature.

f) Maximum temperature and thermal gradient for BP/1300. See Figure 4.

Table 2. Trajectory 14414.1C

TIME SECONDS	BODY POINT 1300 SURFACE T °F
0	250
100	650
200	1,100
300	1,700
400	1,800
450	1,900
500	1,900
600	1,870
700	1,800
800	1,630
900	1,530
1,000	1,420
1,100	1,280
1,200	1,120
1,300	1,000
1,400	1,050
1,500	650
1,600	280
1,700	120
2,000*	120

The typical surface temperature history for body point 1300 of space shuttle trajectory 14414.1C (once around).

* Extended time to ensure no continued temperature rise of the aluminum structure.

Table 3. Typical Time Pressure History for Shuttle Body Point 1300

TIME SECONDS	BODY POINT 1300 PRESSURE LBF/SQ FT
0	0.01087
100	0.08373
200	1.01035
350	17.69237
450	26.51259
550	32.69217
600	37.28221
650	40.55208
700	44.23282
750	43.79233
800	42.45522
850	43.84506
1,050	59.55977
1,150	69.60561
1,200	74.90744
1,250	69.32410
1,300	68.84630
1,350	61.44383
1,400	71.89258
1,450	66.87845
1,500	76.15733
1,550	91.65157
1,600	115.08743
1,650	171.99934
1,750	2116.217
2,000*	2116.217

* Extended time to ensure no continued temperature rise of the aluminum structure.

Table 4. Candidate Materials for Thermal Protection System
(1 to 10 listed in order of 1,366°K (2,000°F) 100 hour Creep Rupture Specific Strengths)

	MATERIAL	100 HR CREEP RUPTURE STRENGTH Mpa (ksi)		SHORT TIME U.T.S. Mpa (ksi)		DENSITY g/cm^3 (lb/in^3)	1,366°K (2,000°F)/100 HR CREEP RUPTURE SPECIFIC STRENGTH MPa/gcm^{-3} $ksi/lb\ in^{-3}$	MAIN ALLOY CONSTITUENT
		1,366°K (2,000°F)	1,255°K (1,800°F)	1,366°K (2,000°F)	1,255°K (1,800°F)			
A	Rene 41	N.A.	69 (10.0)	N.A.	276 (40)	8.25 (0.298)	N.A.	Nickel
B	T.D. Ni	48 (7)	66 (9.5)	90 (13)	110 (16)	8.86 (0.320)	5.46 (21.9)	Nickel
C	T.D. Ni-Cr	55 (8)	72 (10.5)	131 (19)	179 (26)	8.47 (0.306)	6.51 (26.1)	Nickel
1	INCOLOY 802	21 (3.0)	48 (7.0)	83 (12)	115 (17)	7.83 (0.283)	2.64 (10.6)	Iron
2	INCONEL 617	19 (2.7)	41 (6.0)	83 (12)	150 (22)	8.36 (0.302)	2.22 (8.9)	Nickel
3	L605 (= Haynes 25)	19 (2.8)	48 (7.0)	131 (19)	235 (34)	9.13 (0.330)	2.12 (8.5)	Cobalt
4	Haynes 188	15 (2.2)	41 (6.0)	131 (19)	255 (37)	9.13 (0.330)	1.67 (6.7)	Cobalt
5	INCONEL 625	12 (1.8)	32 (4.6)	76 (11)	140 (20)	8.44 (0.305)	1.47 (5.9)	Nickel
6	Nimonic 86	12 (1.7)	31 (4.5)	97 (14)a	237 (34)b	8.53 (0.308)	1.37 (5.5)	Nickel
7	INCONEL 601	11 (1.6)	23 (3.4)	34 (5)	62 (9)	8.05 (0.291)	1.37 (5.5)	Nickel
8	Haynes 556	11 (1.6)	32 (4.7)	97 (14)	185 (27)	8.22 (0.297)	1.35 (5.4)	Iron
9	INCONEL 600	10 (1.4)	19 (2.8)	N.A.	76 (11)	8.41 (0.304)	1.15 (4.6)	Nickel
10	HASTELLOY X	8 (1.2)	26 (3.8)	90 (13)	150 (22)	8.22 (0.297)	0.9 (4.0)	Nickel

a - 1,323°K (1,922°F)
b - 1,173°K (1,652°F)

N.A. - Not Available
A - Precipitation Hardened Superalloy
B-C - Oxide Dispersed Alloys
1-10 - Solid Solution Strengthened Superalloys

Table 5. Thermophysical Properties of INCONEL 617 Honeycomb (4-20 Core) Thickness 0.293 Inch

T (°F)	Cp (BTU/LB-°F)
78.	0.100
200.	0.104
400.	0.111
600.	0.117
800.	0.124
1000.	0.131
1200.	0.137
1400.	0.144
1600.	0.150
2000.	0.163

T °F	k* (BTU/FT-HR-°F)
100.	0.1482
200.	0.1666
400.	0.2041
600.	0.2512
800.	0.3107
1000.	0.3846
1200.	0.4755
1400.	0.5858
1600.	0.7178
1800.	0.8738
2000.	1.0565

* Effective Thermal Conductivity calculated by standard methods (see Reference 15)

INCONEL Density = 521.0 lbs/ft^3

ε external = 0.80 ε internal = 0.60

Table 6. Thermophysical Properties of DYNAFLEX

T (°F)	Cp (BTU/LB-°F)
240	0.202
440	0.233
640	0.252
840	0.267
1040	0.274
1240	0.280
1640	0.284

T °F	P PSF: 0.0278	0.2785	2.785	27.85	139.2	278.4	2116
	k (BTU/HR-FT-°F)						
200	0.0043	0.0048	0.0088	0.0178	0.0206	0.0211	0.0215
400	0.0106	0.0111	0.0150	0.0261	0.0306	0.0313	0.0320
600	0.0173	0.0177	0.0214	0.0342	0.0403	0.0414	0.0425
800	0.0255	0.0259	0.0294	0.0433	0.0512	0.0327	0.0542
1000	0.0369	0.0373	0.0406	0.0553	0.0649	0.0669	0.0688
1200	0.0530	0.0534	0.0566	0.0718	0.0830	0.0854	0.0879
1400	0.0706	0.0710	0.0740	0.0896	0.1023	0.1052	0.1083
1600	0.0930	0.0933	0.0962	0.1119	0.1262	0.1296	0.1333
1800	0.1156	0.1159	0.1187	0.1345	0.1501	0.1540	0.1583
2000	0.1466	0.1469	0.1496	0.1654	0.1823	0.1867	0.1917
2200	0.1827	0.1829	0.1855	0.2013	0.2193	0.2243	0.2300
2400	0.2173	0.2175	0.2200	0.2358	o.2549	0.2606	0.2670

Density = 6.0 lbs/ft ^{3}

Reference: Manufacturer Brochure for 2116 PSF Values. The k values at other pressures are estimated by methods of References 16 and 17.

Table 7. Thermophysical Properties of Q FIBER FELT

T (°F)	Cp (BTU/LB-°F)
240	0.202
440	0.233
840	0.267
1040	0.274
1240	0.280
1640	0.2845

T °F	P PSF	k (BTU/HR-FT-°F) 0.0278	0.2785	2.785	27.85	139.2	278.4	2116
100		0.0020	0.0030	0.0085	0.0155	0.0168	0.0170	0.0172
200		0.0050	0.0059	0.0116	0.0201	0.0220	0.0223	0.0225
300		0.0078	0.0087	0.0145	0.0244	0.0268	0.0272	0.0275
400		0.0107	0.0116	0.0174	0.0285	0.0316	0.0321	0.0325
600		0.0181	0.0188	0.0246	0.0380	0.0425	0.0432	0.0438
800		0.0267	0.0274	0.0330	0.0483	0.0541	0.0551	0.0560
1000		0.0364	0.0370	0.0425	0.0592	0.0665	0.0678	0.0690
1200		0.0476	0.0483	0.0534	0.0713	0.0802	0.0818	0.0833
1400		0.0624	0.0635	0.0685	0.0876	0.0981	0.1001	0.1020
1500		0.0765	0.0770	0.0820	0.1015	0.1127	0.1149	0.1170

Density = 3.5 lb/ft^3

Reference: Manufacturer Brochure for 2116 PSF Values. The k values at other pressures are estimated by methods of References 16 and 17.

Table 8. Thermophysical Properties of Titanium Honeycomb (3-20 Core) Thickness 0.185 Inch

T (°F)	Cp (BTU/LB-°F)
0.	0.140
200.	0.140
400.	0.145
600.	0.148
800.	0.155
1000.	0.166

T °F	k* (BTU/FT-HR-°F)
0.	0.0651
100.	0.0764
200.	0.0883
400.	0.1133
600.	0.1413
800.	0.1754
1000.	0.2149

* Effective Thermal Conductivity calculated by standard methods (see Reference 15)

Titanium Density = 281.5 lb/ft^3

ε external = 0.80 ε internal = 0.18

**Aluminum properties used were:

density = 169 lb/ft^3
C_p = 0.229 BTU/lb - °F

Table 9. Thermophysical Properties of MIN-K

T °F	k (BTU/FT-HR-°F)
100.	0.0145
200.	0.0148
300.	0.0153
400.	0.0159
500.	0.0166
1200.	0.0225

Reference: Manufacturers Brochure

Table 10. Boundary Temperatures Used and Comparison of Predicted and Measured Steady State Temperatures

MEASURED BOUNDARY TEMPERATURES T_1	T_{17}	$T13_T$ MEASURED	$T13_A$ ANALYTICAL PREDICTION	PERCENT ERROR $\frac{(T13_A - T13_T)}{T13_T} \times 100$	Q_A * BTU/HR ANALYTICAL PREDICTION	Q_T ** BTU/HR TEST
			CENTER OF TILE			
305.5	90.3	190.7	189.2	-0.78	17.38	17.61
605.8	123.6	385.2	391.7	1.68	48.6	47.31
896.2	154.9	610.0	618.2	1.34	88.65	86.25
1189.2	201.8	866.2	871.8	0.65	137.2	134.58
1474.9	265.9	1139.8	1136.3	-0.31	191.88	192.00
1799.4	354.5	1461.5	1445.9	-1.07	258.91	266.18
			ADJACENT TO SIDEWALL			
305.5	90.3	198.8	203.7	2.46	19.93	19.05
605.8	123.6	397.6	416.5	4.75	53.44	49.65
896.2	154.9	615.1	647.5	5.27	94.89	87.31
1189.2	201.8	877.0	902.0	2.85	144.38	137.17
1474.9	265.9	1155.5	1165.5	0.86	199.61	196.16
1799.4	354.5	1476.0	1472.3	-0.25	266.10	270.50

* Based on predicted temperature at T_{13}

** Based on measured temperature at T_{13}

Table 11. Structural Test Summary

TEST TYPE	PRETEST ELEVATED TEMP. EXPOSURE	ELEVATED TEMP. TESTS	NUMBER OF SPECIMENS
Face Sheet Tension[1]	Yes	Yes	61
Face Sheet Creep[1]	No	Yes	16
Edgewise Compression[2]	No	No	35
Flatwise Tension[2]	Yes	Yes	30
Full Panel Pressure/Temperature Gradient	No	Yes	1

1 Test specimens are INCONEL foil material both as-received and after process/brazing

2 Test specimens are INCONEL brazed sandwich

Table 12. INCONEL 617 Face Sheet Tension Tests - No Pretest Environmental Exposure - Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty[1] MPA (KSI)	Ftu[1] MPA (KSI)	e[1] %	E[1] GPA (KSI x 10^3)
A-1 As-Received	0.076 (0.003)	5	Room Temp.	582 (84.4)	889 (129.0)	12.1	221. (32.0)
A-2 As Received[2]	0.076 (0.003)	5	Room Temp	583 (84.5)	1007 (146.1)	34.3	195.5 (28.3)
B. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	Room Temp.	478 (69.3)	836 (121.3)	2.7	184 (26.7)
C. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1089 (1500)	226 (32.8)	468 (67.9)	5.5	98.6 (14.3)
D. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1255 (1800)	118 (17.1)	219 (31.7)	10.7	77.2 (11.2)
E. Processed/Brazed to Honeycomb Core	0.127 (0.005)	4	1255 (1800)	139 (20.1)	219 (31.7)	22.3	110.0 (16.1)
F. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	45 (6.5)	62 (9.0)	3.0	21.0 (3.05)

1 Average values.

2 This is a repeat of A-1 tests with specimens more carefully prepared and load rates reduced to 0.51 mm (0.02 inches) per minute crosshead speed.

Table 13. INCONEL 617 Face Sheet Tension Tests - 5 Hours of 2,000°F Pretest Exposure - Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty MPA (KSI)	Ftu MPA (KSI)	e %	E GPA (KSI x 10^3)
E. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	Room Temp.	412. (59.8)	585. (84.9)	1.6	219. (31.7)
H. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1255 (1800)	127. (18.4)	148. (21.5)	2.3	72.4 (10.5)
I. Processed/Brazed to Honeycomb Core	0.127 (0.005)	5	1255 (1800)	137. (19.8)	174. (25.3)	8.3	77.9 (11.3)
F. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	37. (5.3)	39. (5.7)	1.5	19.2 (2.78)

Table 14. INCONEL 617 Face Sheet Tension Tests - 25 Hours of 2,000°F Pretest Exposure Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty MPA (KSI)	Ftu MPA (KSI)	e %	E GPA (KSI x 10^3)
K. Processed/Brazed to Honeycomb Core	0.076 (0.003)	2	Room Temp.	388.0 (56.2)	404.0 (58.6)	0.6	216.0 (31.4)
L. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	41.0 (6.0)	46.0 (6.7)	1.2	32.0 (4.64)

Table 15. Creep Tests - INCONEL 617 (0.003 Inch Foil)

SPECIMEN CONFIGURATION	SPECIMEN SIZE (inch)	TEST TEMPERATURE	NUMBER OF SPECIMENS
Sheet Material As-Received	1/4 x 2 x 0.003	1500°F	6
Processed/Brazed to Honeycomb Core	1/4 x 2 x 0.003	1500°F	5
Processed/Brazed to Honeycomb Core	3/4 x 3 x 0.003	1800°F	2
Processed/Brazed to Honeycomb Core	3/4 x 3 x 0.003	2000°F	3(a)
TOTAL			16

(a) Some other tests were conducted at this temperature with the smaller (1/4 inch x 2 inch) test specimens. However, the test results were considered invalid and are not reported.

Table 16. INCONEL 617 Creep Rupture Test Results

	SPECIMEN NO.	STRESS (KSI)	TEMPERATURE (°F)	TIME (HRS.)	P = (460 + T) (20 + log t)10^{-3}
AS REC'D MATERIAL	1A	20.0	1500	20.0	41.8
	2A	20.0	1500	19.5	41.7
	3A	17.0	1500	29.9	42.1
	4A	13.0	1500	167.3[2]	43.6
	5A	15.0	1500	107.1	43.2
	6A	17.0	1500	44.5	42.4
BRAZED SANDWICH FACE SHEET	1C	17.0	1500	116.2[2]	43.2
	2C	21.0	1500	32.0	42.2
	3C	21.0	1500	63.6	42.7
	4C	21.0	1500	69.8	42.8
	5C	20.0	1500	98.3	43.1
	N1 [1]	1.0	2000	90.0	54.0
	N2 [1]	1.0	2000	330.4	55.4
	N4 [1]	6.0	1800	46.8	49.7
	N5 [1]	6.0	1800	53.7	49.1
	N6 [1]	2.0	2000	92.3	54.0

1 These specimens have 3/4 inch wide test area while others have 1/4 inch wide test area.

2 No Failure

P = Larson-Miller Parameter

T = Temperature, °F

t = Time, hrs.

Table 17. Edgewise Compression - INCONEL 617 Sandwich (See Figure 43)

SPECIMEN CONFIGURATION	NUMBER OF SPECIMENS	Fcu[1] (KSI)
0.003 inch Face Sheet, 3/16 inch with 0.002 inch Core	5	57.0
0.003 inch Face Sheet, 1/4 inch with 0.002 inch Core	5	43.8
0.003 inch Face Sheet, 3/8 inch with 0.002 inch Core	5	28.3
0.003 inch Face Sheet, 3/16 inch with 0.0015 inch Core	5	53.0
0.005 inch Face Sheet, 3/16 inch with 0.002 inch Core	5	60.1
0.005 inch Face Sheet, 1/4 inch with 0.002 inch Core	5	52.5
0.005 inch Face Sheet, 3/8 inch with 0.002 inch Core	5	39.3
TOTAL	35	

1 These are average values

2 Testing was performed at room temperature

Table 18A. Explanation of Panel Identification Number

XFT-Y

<u>X</u> - Panel Configuration

<u>FT</u> - Type of Test - Flatwise Tension

<u>Y</u> - Test Conditions

<u>TEST CONDITIONS</u>

Y	Pre-Test Environment	Test Temperature	Material Processing Status
A	None	Room Temperature	As Received
B	None	Room Temperature	Brazed
C	None	1500°F	Brazed
D	None	2000°F	Brazed
E	5 Hours @ 2000°F air furnace	Room Temperature	Brazed
F	5 Hours @ 2000°F air furnace	2000°F	Brazed
G	25 Hours @ 2000°F air furnace	Room Temperature	Brazed
H	25 Hours @ 2000°F air furnace	2000°F	Brazed

Table 18B

PANEL CONFIGURATION

X	Face Sheet Thickness (Inches)	Core Cell Size (Inches)	Core Foil Thickness (Inches)
A*	0.003	3/16	0.002
B	0.003	1/4	0.002
C	0.003	3/8	0.002
D	0.005	3/16	0.002
E*	0.005	1/4	0.002
F	0.005	3/8	0.002
G*	0.003	3/16	0.0015

* Only these configurations were selected for flatwise tension testing

Table 19. Flatwise Tension Tests
(3-Inch by 3-Inch One-Layer INCONEL 617 Honeycomb Core Sandwich)

PANEL IDENTIFICATION [1]	PRE-TEST ENVIRONMENT	TEST TEMPERATURE	NUMBER OF SPECIMENS	AVERAGE FLATWISE TENSION STRENGTH (PSI
AFT - B	None	Room Temperature	10	Note: C-Scans of many of the specimens from panels AFT and GFT indicated defective braze joints. Test results are not reported.
GFT - B	None	Room Temperature	10	
GFT - C	None	1,500°F	5	
GFT - D	None	2,000°F	5	
EFT - B	None	Room Temperature	10	1682
EFT - E	5 Hours @ 2,000°F Air Furnace	Room Temperature	5	799
EFT - G	25 Hours @ 2,000°F Air Furnace	Room Temperature	10	213
EFT - H	25 Hours @ 2,000°F Air Furnace	2,000°F	5	18 [2]
TOTAL			60	

PANEL CONFIGURATION	FACE SHEET THICKNESS (INCHES)	CORE CELL SIZE (INCHES)	CORE FOIL THICKNESS (INCHES)
A	0.003	3/16	0.002
G	0.003	3/16	0.0015
E	0.005	1/4	0.002

1 See Table 18A for explanation.
2 These specimens were severely warped by the 25-hour furnace exposure and consequently the brazed loading blocks cause highly concentrated loads.

Table 20. Panel Deflections - Analytical versus Test

LOADING CONDITION	LOCATION		
	CENTER OF PANEL[1]	MIDDLE OF EDGE OF PANEL[2]	CORNER OF PANEL[3]
A. 2 psi Blowoff - Room Temperature			
Analytical	0.147 Inch	0.117 Inch	0.120 Inch
Test	0.098 Inch	0.078 Inch	0.044 Inch
B. 2 psi Crush Room Temperature			
Analytical	-0.032 Inch	0.001 Inch	0.005 Inch
Test	-0.039 Inch	0.017 Inch	0.008 Inch
C. Max. Thermal Gradient			
Analytical (1900°F)(203°F)	0.093 Inch	0.055 Inch	0.016 Inch
Test (2000°F)(400°F)	0.138 Inch	0.067 Inch	0.049 Inch

1) Grid #1120 (see Figure 50); Dial Indicator #3 (see Figure 65)

2) Grid #1126 (see Figure 50); Dial Indicator #5 (see Figure 65)

3) Grid #616 (see Figure 50); Dial Indicator #1 (see Figure 65)

Table 21A. Ascent Conditions (Ref. Table 1)
Stress Levels and Margins of Safety

COMPONENT	ASCENT CONDITION		ASCENT ALLOWABLE (PSI)	FAILURE MODE	MINIMUM MARGIN OF SAFETY
	STRESS (CRUSH) (PSI)	STRESS (BLOWOFF) (PSI)			
INCONEL Sandwich	-9,700[a]	-11,500[a]	41,000[b]	Intracell Buckling	+2.57
INCONEL Sidewall	-7,690[c]	5,540[c]	48,700[d]	Axial and Shear	+5.33
Titanium Sandwich	-2,900[e]	-14,900[f]	24,000[g]	Intracell Buckling	+0.61
Titanium Clip	0	180,500[h]	183,300[i]	Bending	+0.02
Titanium Clip	0	120,300[j]	140,400[k]	Bending	+0.17

(+) Tension

(-) Compression

a) QUAD4 Element ID 1021, principal stress

b) Intracell Buckling Allowable @ T = 600°F Ref. Figure 52

c) Shear 103, Bars 103 and 104 (shear stress and average stress in two adjacent bars), principal stress

d) Not critical in stability, use F_{ty} at T = 400°F.
Reference Figure 37 (average of 5-hour and 25-hour data.

e) QUAD4 109 (t = 0.006 inch) principal stress

f) QUAD4 210 (t = 0.003 inch) principal stress

g) Intracell Buckling Allowable @ T = 100°F. Reference Figure 53.

h) 2.0 PSI ultimate + temperature environment

i) Ultimate plastic bending allowable + temperature

j) 1.33 psi limit + temperature environment

k) Limit plastic bending allowables + temperature environment.

Table 21B. Descent Conditions (Ref. Table 1)
Stress Levels and Margins of Safety

COMPONENT	DESCENT CONDITION STRESS	DESCENT ALLOWABLE	FAILURE MODE	MINIMUM MARGIN OF SAFETY
INCONEL Sandwich	-9,100[a]	14,500[b]	Intracell Buckling	+0.59
INCONEL Sidewall	-5,200[c]	33,500[d]	Axial and Shear	+5.44
Titanium Sandwich	-9,100[e]	23,200[f]	Intracell Buckling	+1.55
Titanium Clip	0	111,400[g]		High

(+) Tension

(-) Compression

a) Intracell Buckling Allowable @ T = 1869°F (Maximum stress is on inner surface of INCO Honeycomb). Reference Figure 52.

b) Shear Panel 12, Bar 324 and Rod 325 (shear stress and average axial stresses in bar and rod), principal stress.

c) Not critical in stability, use F_{ty} @ T = 1050°F. Reference Figure 37 (average of 5-hour and 25-hour data.

d) QUAD4 210 (t = 0.003 inch).

e) Intracell Buckling Allowable @ T = 200°F Reference Figure 53.

f) Ultimate Plastic Bending Allowable + Temperature.

Table 22. INCONEL Bi-Metal Panel Pressure-Thermal Gradient Test

Condition I	Room Temperature	2 psi (crush)
Condition II	1,000°F/100°F	2 psi (crush)
Condition III	Room Temperature	2 psi (burst)
Condition IV	2,000°F/400°F	-0- psi
Condition V	1,000°F/100°F	2 psi (burst)
Condition VI	1,000°F/100°F	3.6 psi (burst) Panel Air Leak

8 Thermocouples
6 Dial Indicators
Controlled Heatup Rates

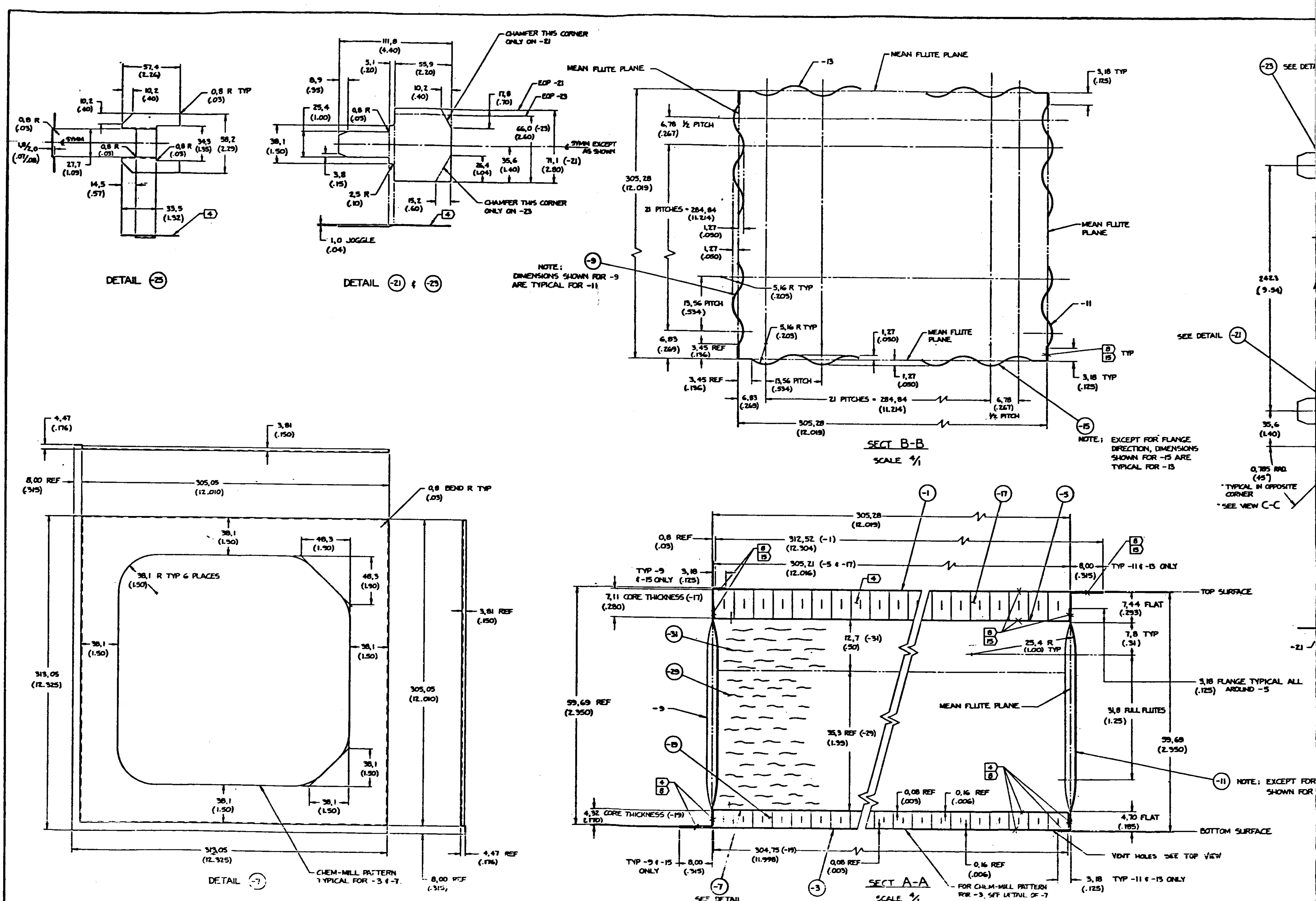
Table 23. Test Panel Temperature Profile During Burst Pressure Test

APPLIED PRESSURE LOAD KPa (PSI)	THERMOCOUPLE READING °K (°F)							
	1	2	3	4	5	6	7	8
6.89 (+1.00)	814.8 (1007)	815.9 (1009)	413 (283)	332 (137)	336 (145)	814.8 (1007)	816.5 (1010)	811.5 (1001)
13.8 (+2.00)	812.6 (1003)	814.8 (1007)	414 (285)	328 (131)	333 (139)	812.6 (1003)	813.7 (1005)	808 (995)
17.2 (+2.50)	813.2 (1004)	822.0 (1020)	416 (289)	323 (121)	330 (134)	813.7 (1005)	818.2 (1013)	817.6 (1012)
20.7 (+3.00)	793 (967)	805 (989)	435 (323)	319 (114)	333 (139)	793 (968)	800 (980)	813.2 (1004)
24.1 (+3.50)	785 (949)	796 (974)	452 (354)	312 (101)	323 (122)	784 (952)	780 (945)	810 (998)
24.8 (+3.60)	834.3 (1043)	855.9 (1081)	435 (324)	310 (93)	312 (102)	837.0 (1047)	855.4 (1080)	820.9 (1018)

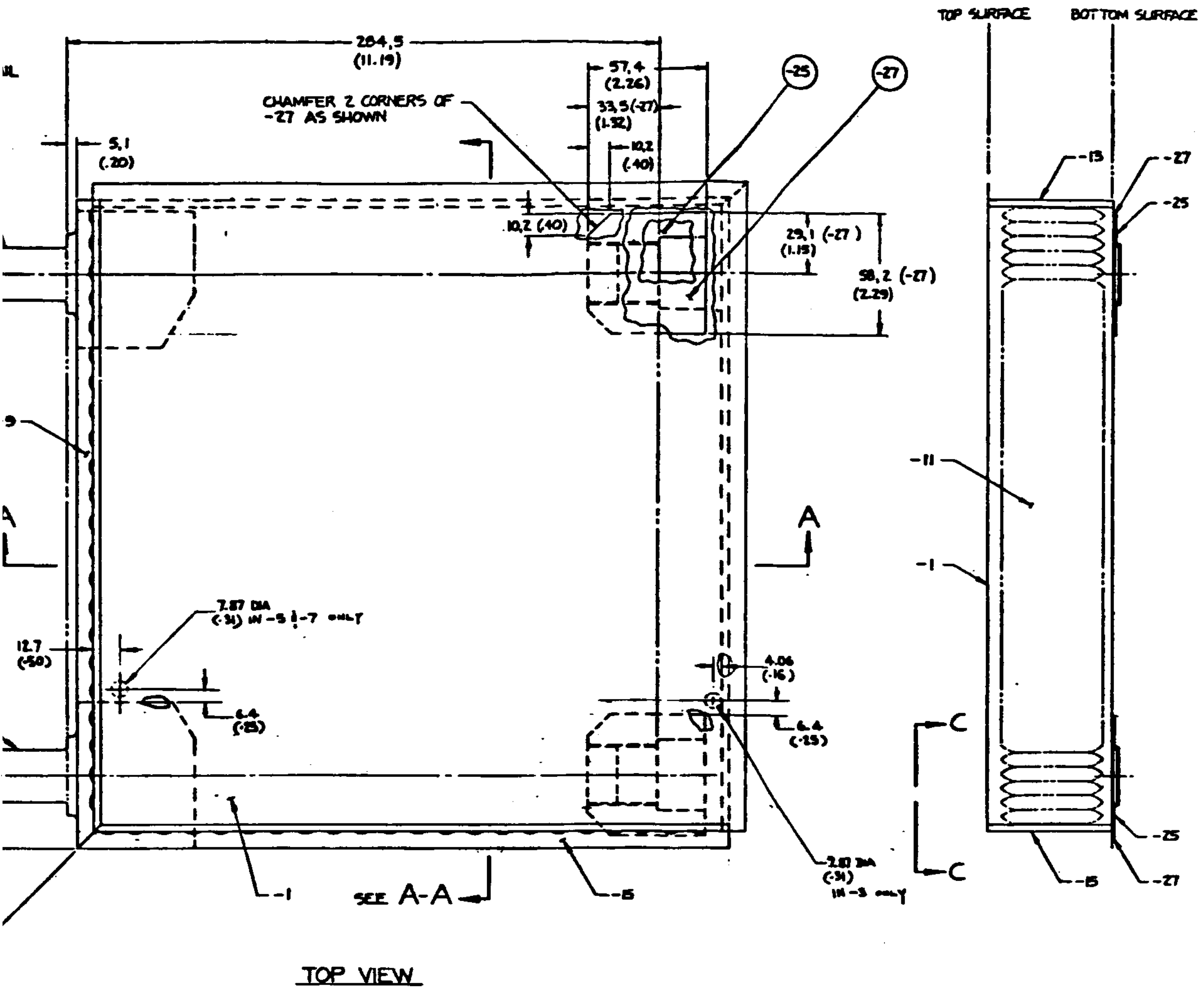
Thermocouples 1,2, 6, 7 and 8 are on the hot outer surface of the panel.

Thermocouple 3 is on the side of the panel.

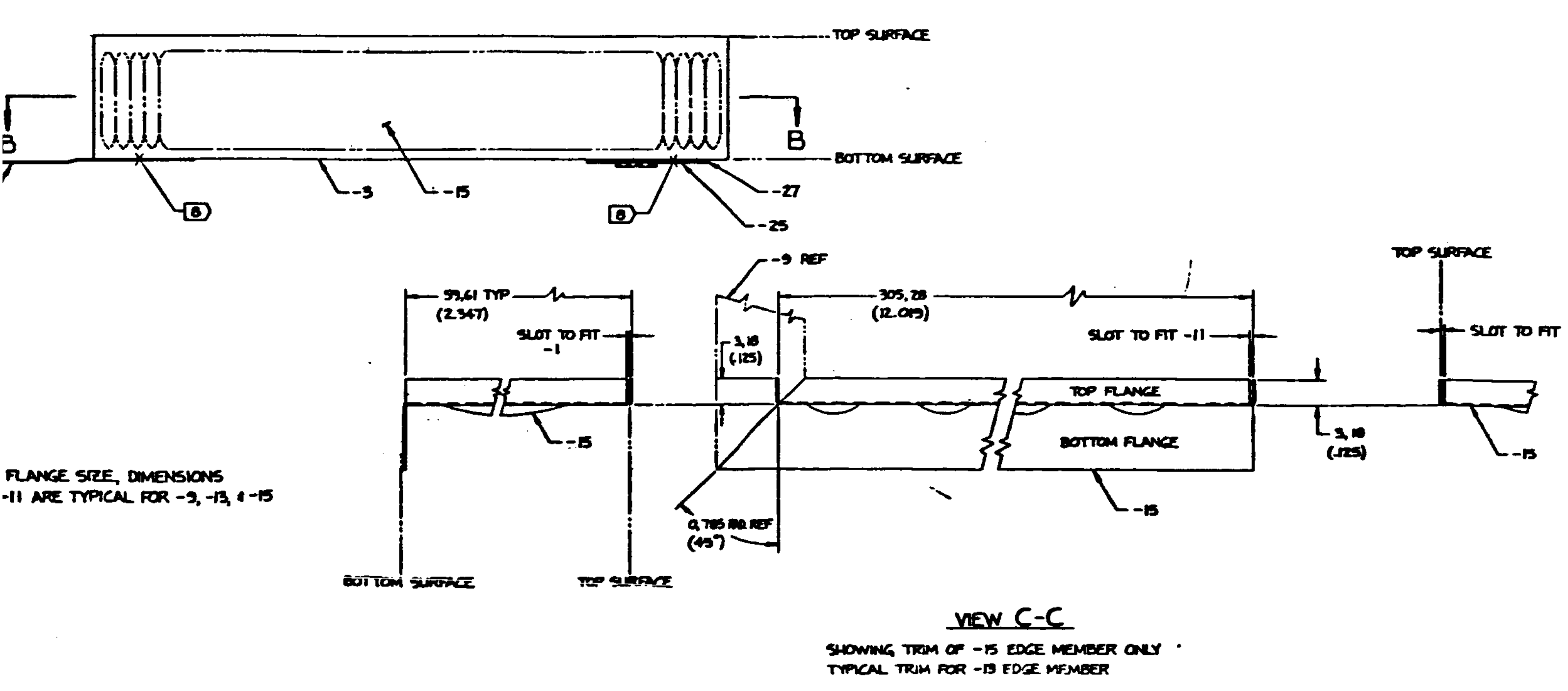
Thermocouples 4 and 5 are on the panel inner surface.



DETAIL (-25)
DETAIL (-21) & (-23)
CHAMFER THIS CORNER ONLY ON -21
CHAMFER THIS CORNER ONLY ON -23
1,0 JOGGLE (.04)
NOTE: DIMENSIONS SHOWN FOR -9 ARE TYPICAL FOR -11
MEAN FLUTE PLANE
SECT B-B
SCALE 4/1
NOTE: EXCEPT FOR FLANGE DIRECTION, DIMENSIONS SHOWN FOR -15 ARE TYPICAL FOR -13
38,1 R TYP 6 PLACES (1.50)
0,8 BEND R TYP (.03)
CHEM-MILL PATTERN TYPICAL FOR -3 & -7.
DETAIL (-7)
7,11 CORE THICKNESS (-17) (.280)
4,32 CORE THICKNESS (-19) (.170)
TOP SURFACE
BOTTOM SURFACE
3,18 FLANGE TYPICAL ALL AROUND -5
31,8 FULL FLUTES (1.25)
VENT HOLES SEE TOP VIEW
FOR CHEM-MILL PATTERN FOR -3, SEE DETAIL OF -7
SEE DETAIL
SECT A-A
SCALE 4/1
SEE DETAIL (-21)
SEE VIEW C-C



195-256-501 REPRESENTS THE BASELINE PANEL. SEE NEXT ASSY 195-256 FOR MODIFICATIONS TO PANELS, NECESSARY TO FIT 20-PANEL ARRAY.



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN S.I. UNITS & (CUSTOMARY UNITS); mm (in.), rad (deg), N/m² (torr), K (°F)
2. TOLERANCES:

LINEAR	X. = ±2	.X = ±.7	.XX = ±.25
	(.X = ±.1	.XX = ±.03	.XXX = ±.010)
ANGULAR	.X = ±.1	.XX = ±.01	.XXX = ±.001
	(X = ±2	.X = ±.5	.XX = ±.05)

3. SEE 195-255 FOR TOOL TO MAKE CLOSURES, -9, -11, -13, & -15
4. LID PLATE THESE SURFACES, & ENTIRE H/C CORE PER RPS 11.89, TYPE B IN PREPARATION FOR BONDING
5. FORM TITANIUM PARTS PER RPS 14.02
6. PROCESS -17 & -19 CORES PER RPS 11.88-9
7. CHEM-MILL TITANIUM PER RPS 14.10. TOLERANCES ±0,03 (±.001). VACUUM DEGASSING MANDATORY
8. SPOTWELD COMPONENTS IN POSITION IN PREPARATION FOR BONDING
9. IDENTIFY ALL PARTS & ASSYS PER RPS 13.99. RUBBER STAMP LOCATION OPTIONAL. IMPRESSION STAMPING NOT PERMITTED
10. PROCESS BOND ASSY PER RPS 11.88
11. BOND IN A VACUUM FURNACE AT A PRESSURE OF .0066 N/m² (5×10^{-6} torr) & TEMPERATURE OF 1214 K (1725°F).
12. OXIDIZE THIS SURFACE ONLY E-8
13. PERMISSIBLE WAVINESS ±0,81 (±.032)
14. CORE MATERIAL PER RMS 110
15. SUPERALLOY L.I.D. BOND PER RPS (TBD)

QTY REQD	PART NO.	DESCRIPTION	MATERIAL	SIZE (in.)	SPEC	HT
A/R	-31	CERACHROME 96.12 Kg/m³ (6.0 LB/FT³)				
A/R	-29	Q-FIBER FELT 56.07 Kg/m³ (3.5 LB/FT³)				
2	-27	DOUBLER	TI-6AL-4V	.020 × 3 × 3	AMS 4911	
2	-25	CLIP		.020 × 3 × 3		
1	-23	TONGUE		.032 × 3 × 5		
1	-21	TONGUE	TI-6AL-4V	.032 × 3 × 5	AMS 4911	
1	-19	CORE 3-20-RCB	TI-3AL-2.5V	.170 × 13 × 13	14	
1	-17	CORE 4-20-RB-P	INCO 617	.280 × 13 × 13	14	
1	-15	CLOSURE		.003 × 4 × 14		
1	-13					
1	-11					
1	-9	CLOSURE	INCO 617	.003 × 4 × 14		
1	-7	SEPTUM - LOWER	TI-6AL-4V	.006 × 14 × 14	AMS 4911	
1	-5	SEPTUM - UPPER	INCO 617	.005 × 13 × 13		
1	-3	SKIN - LOWER	TI-6AL-4V	.006 × 13 × 13	AMS 4911	
1	-1	SKIN - UPPER	INCO 617	.005 × 13 × 13		
X	-501	PANEL ASSY 16				

INDUSTRIES, INC.
PANEL ASSY-
NASA T.P.S.
J 51553 195-256

Figure 1-A. Panel Assembly

2

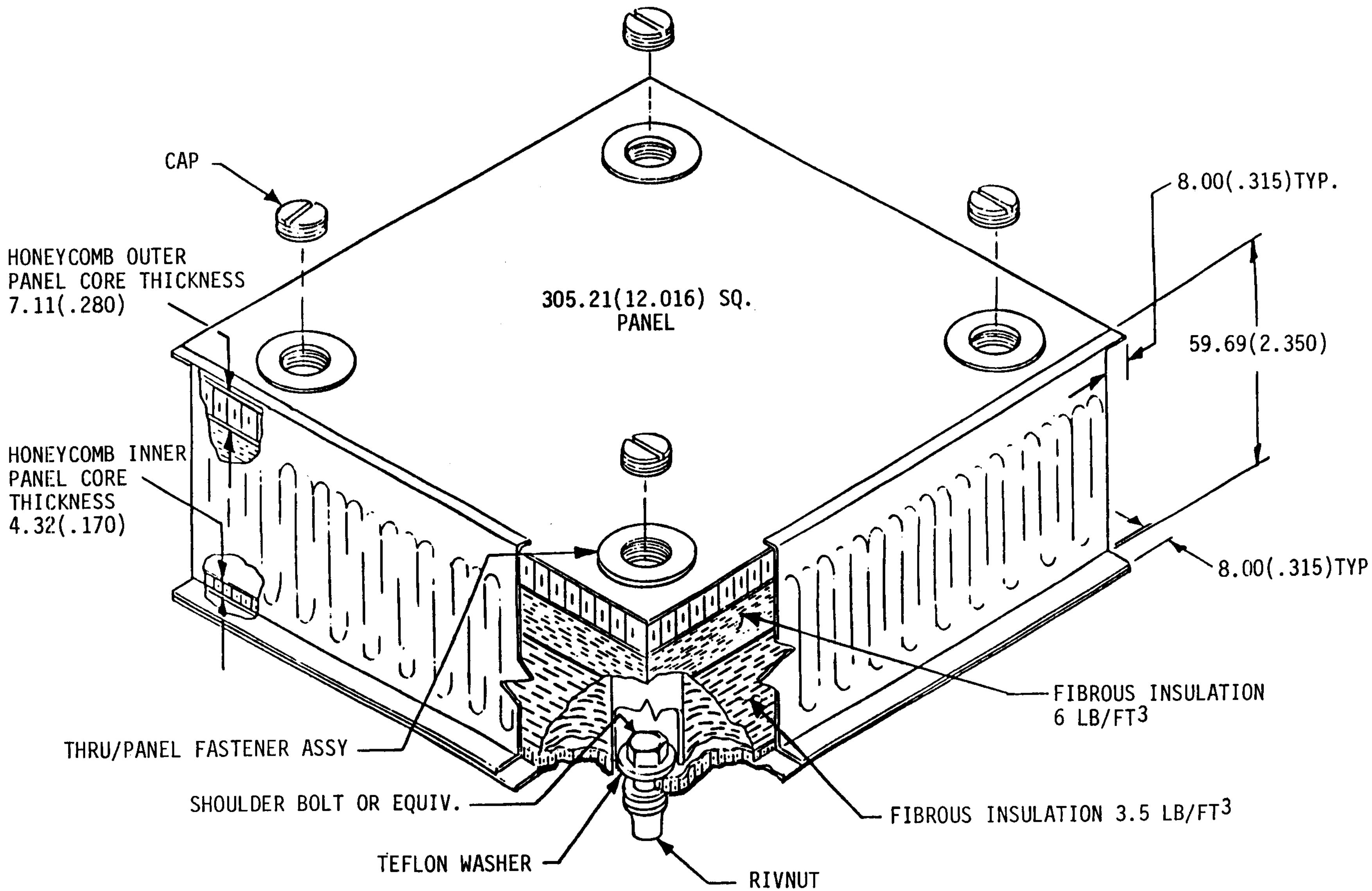


Figure 1-B. Schematic of Bi-Metal Silica Sandwich Panel

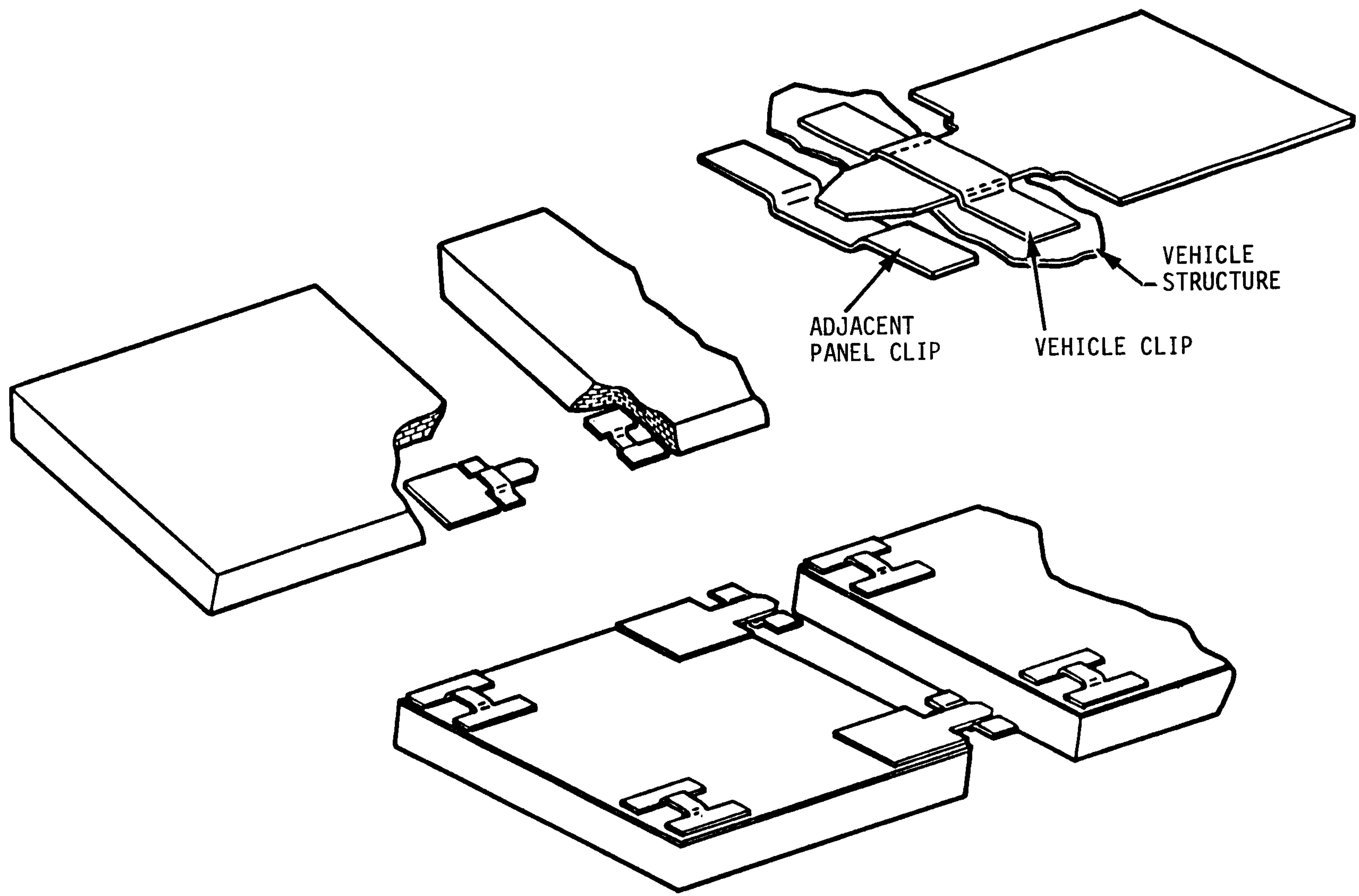


Figure 2. Bayonet Attachment Scheme

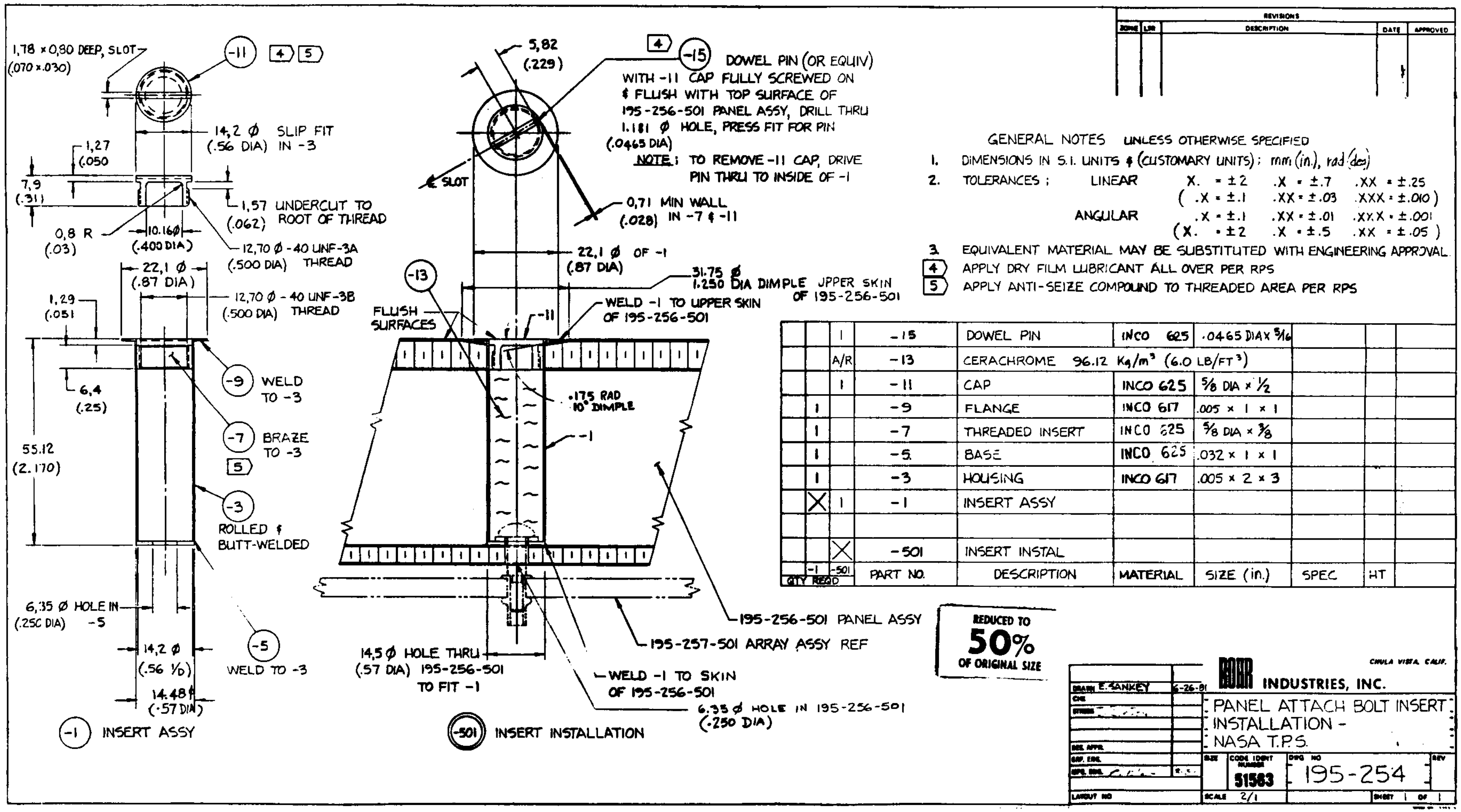


Figure 3. Panel Attach Bolt Insert Installation

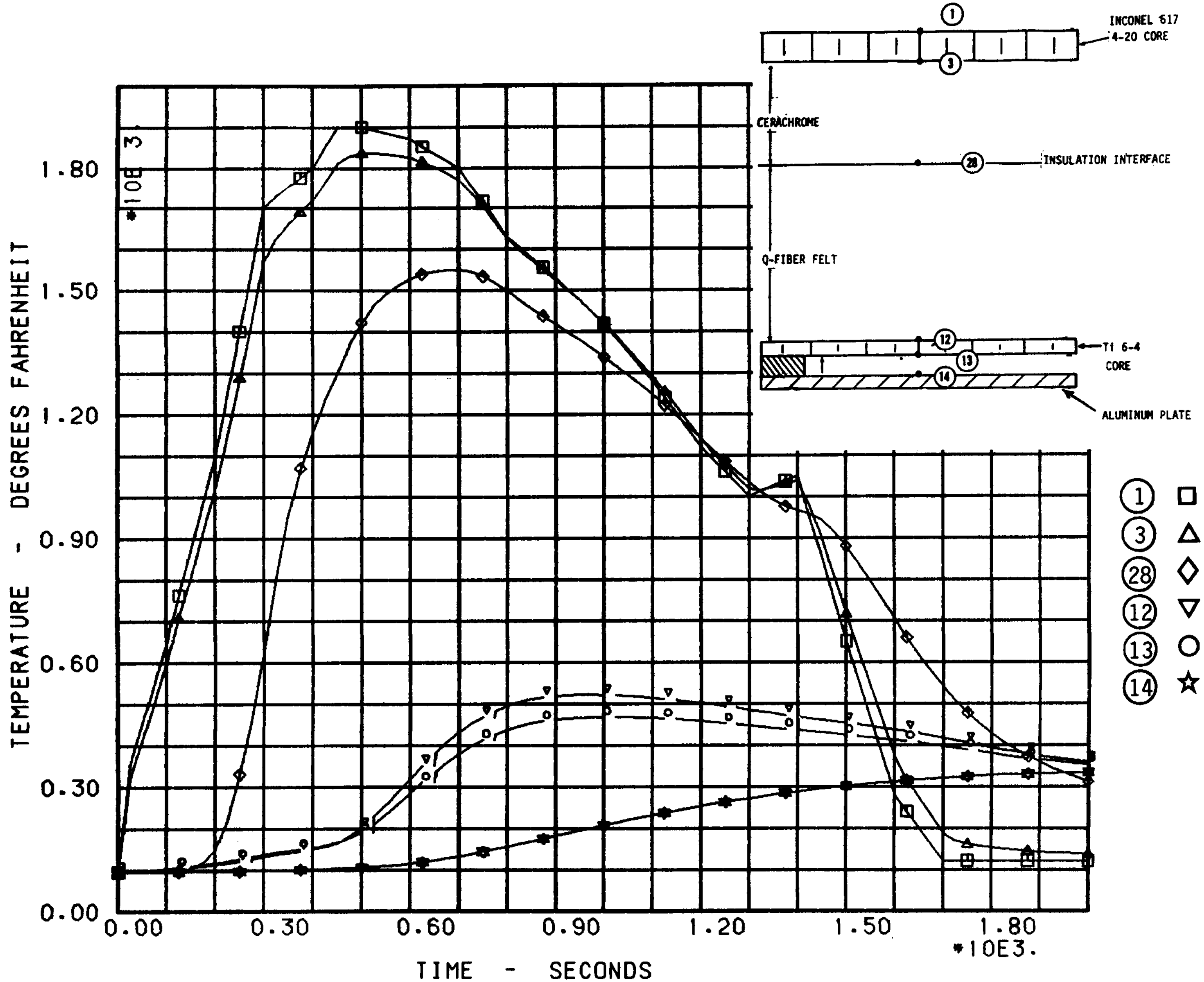


FIGURE 4 TYPICAL RESULTS FOR TRANSIENT ANALYSIS

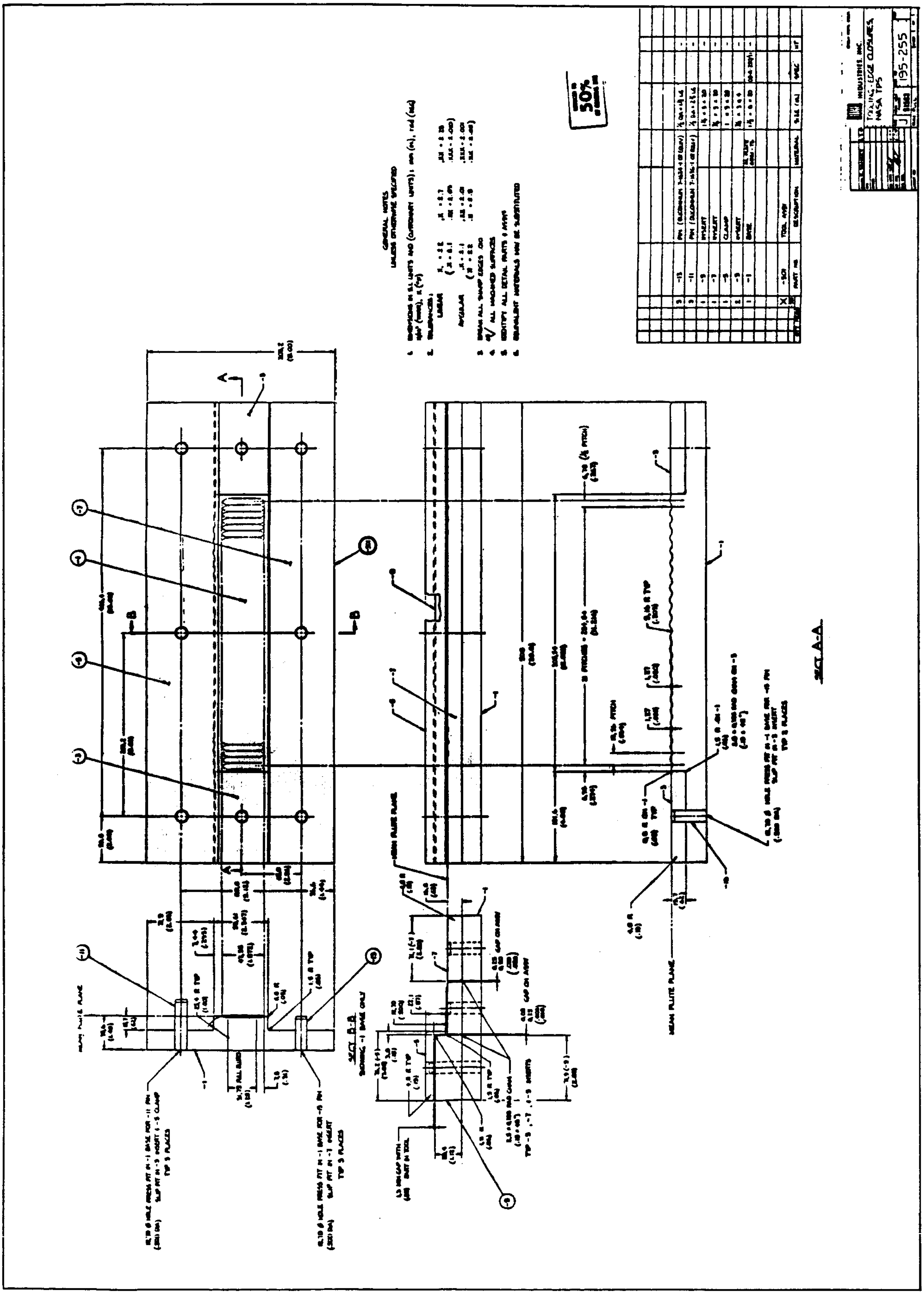


Figure 5. Edge Closure Tool

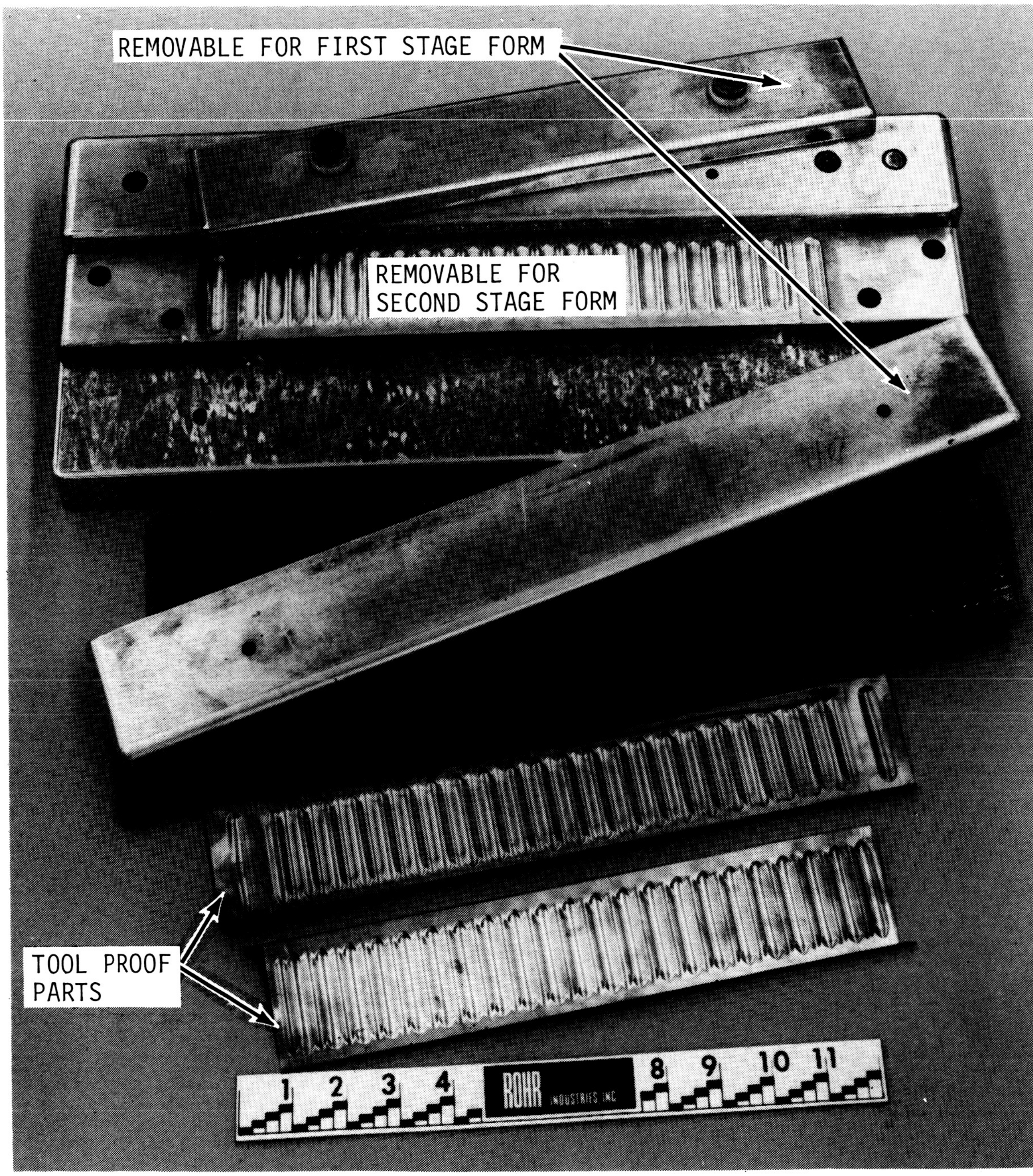


Figure 6. 6061 Aluminum Form Block With Removable Details and Tool Proof Parts

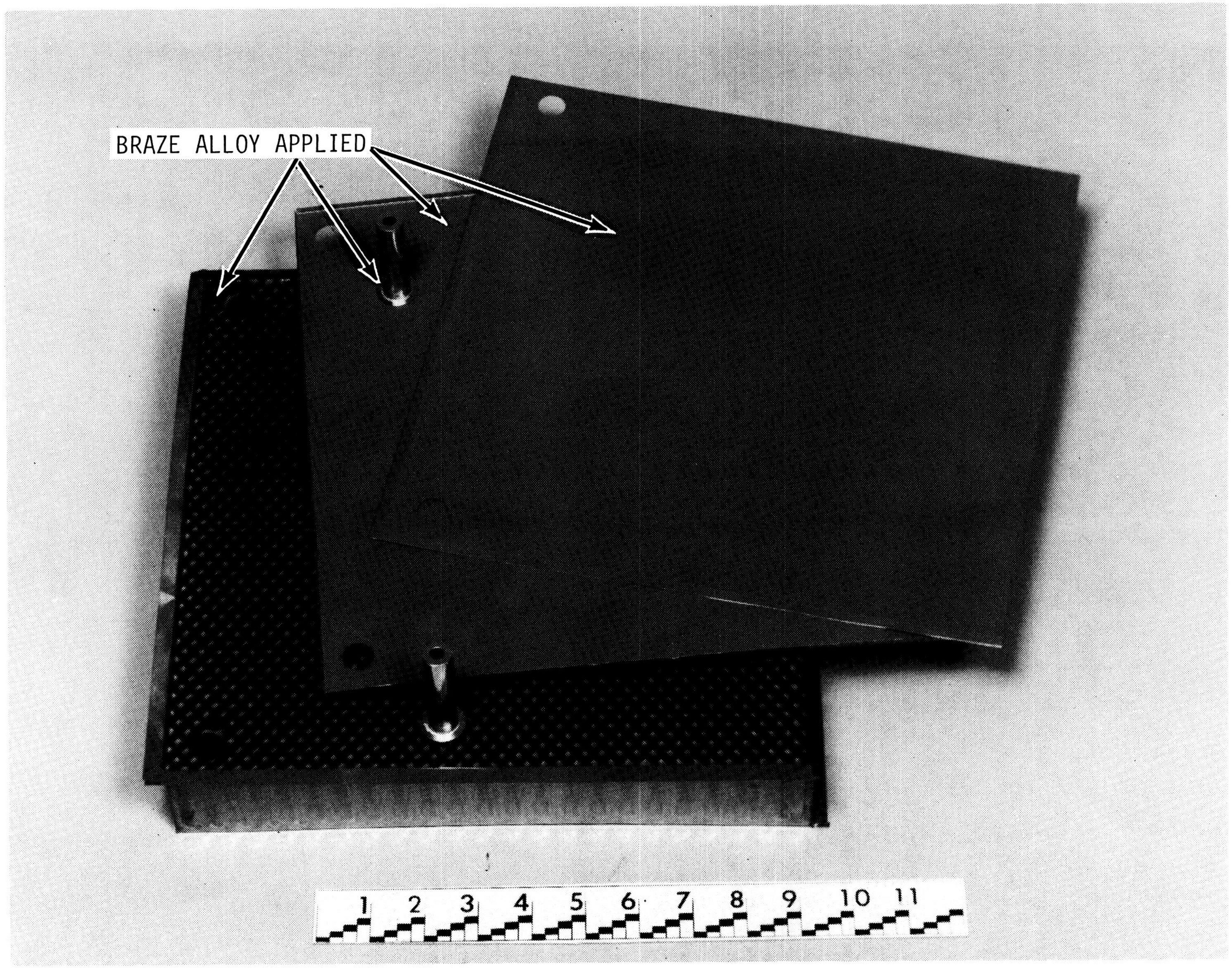


Figure 7. Braze Alloy Applied to all Interfaces

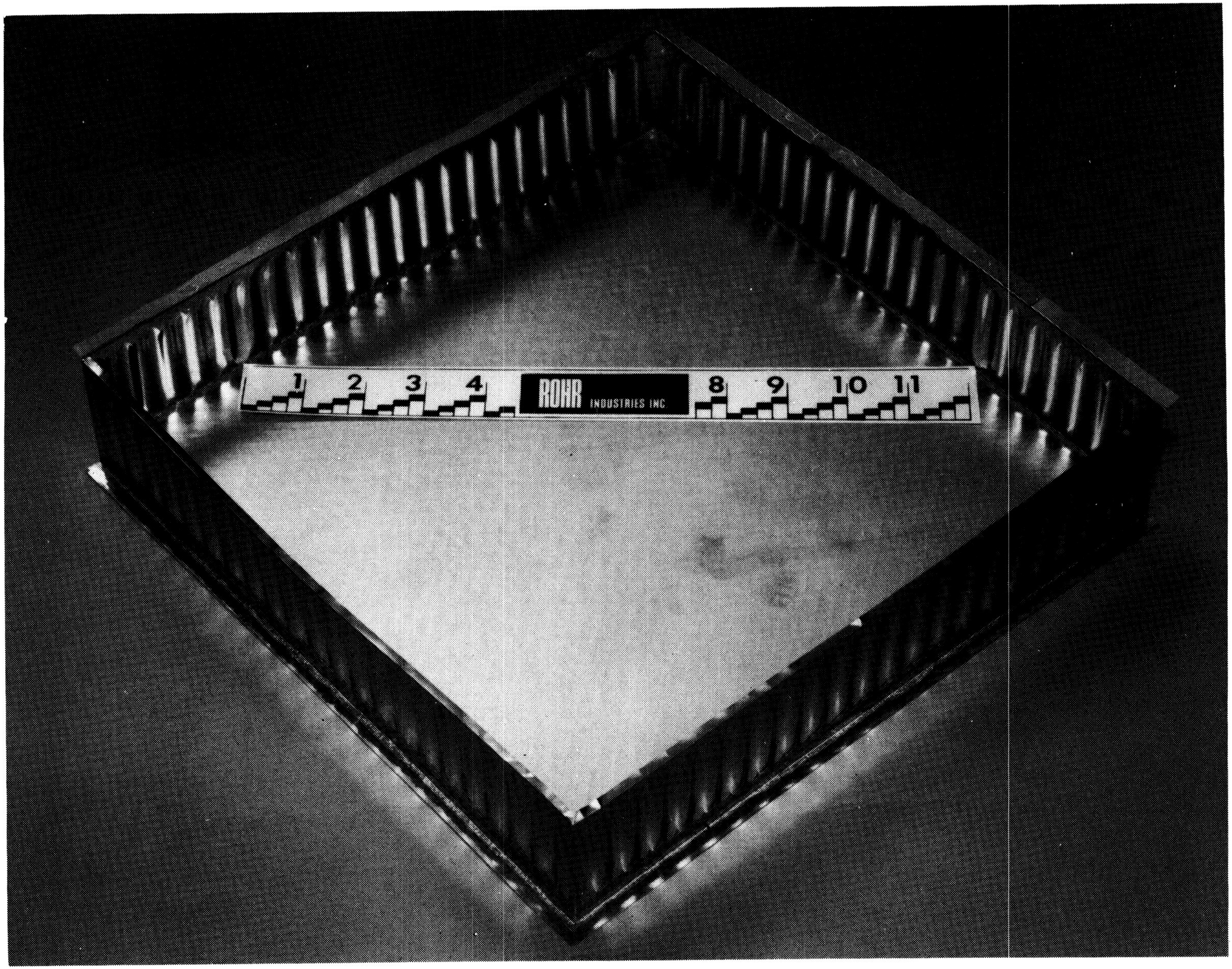


Figure 8. INCONEL 617 Subassembly after Brazing/Diffusion Bonding

Figure 9. Tool Proof Parts (Un-Trimmed Titanium Skins) Being Removed from SPF Tool

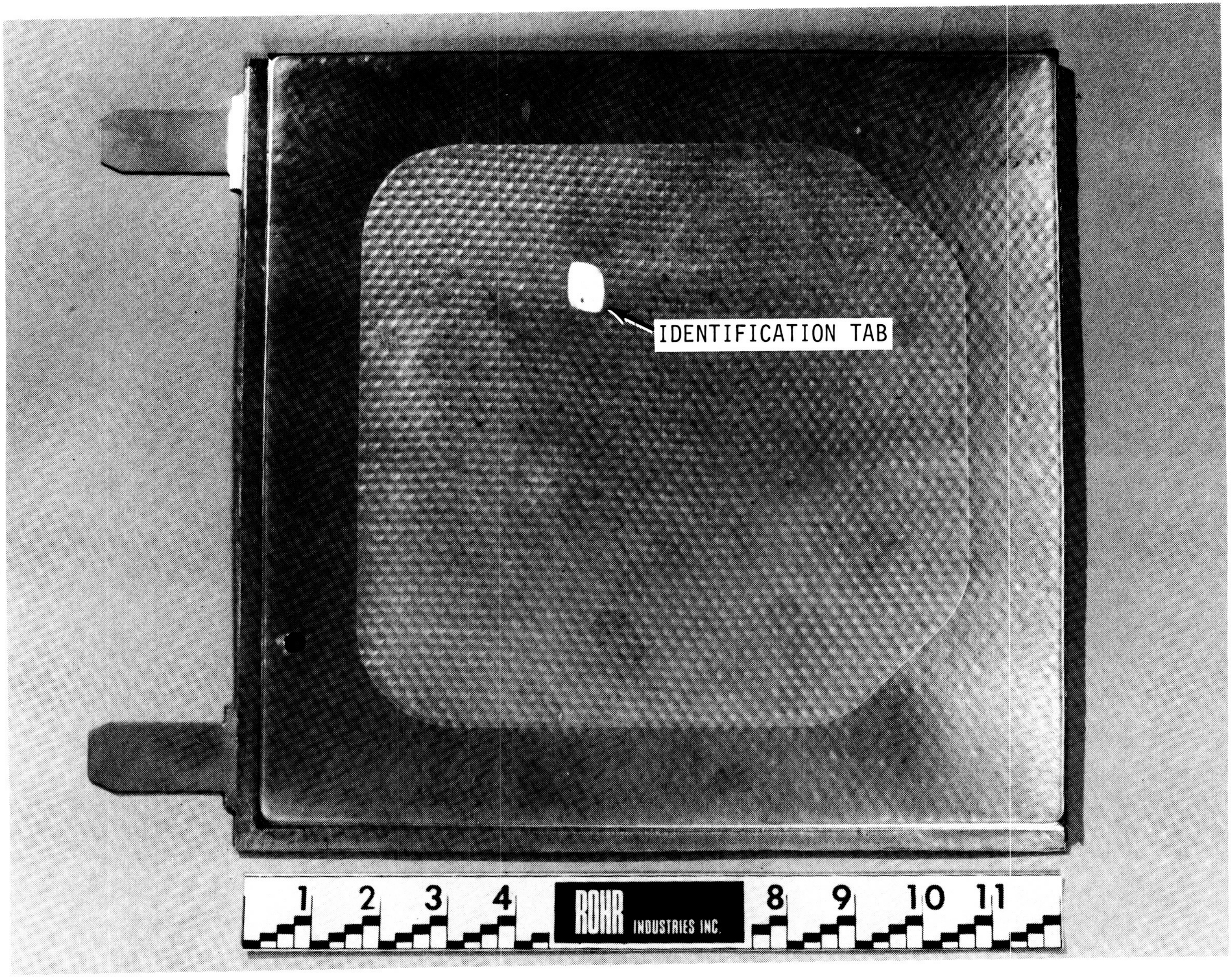


Figure 10. Top of Titanium Subassembly after LID Bonding

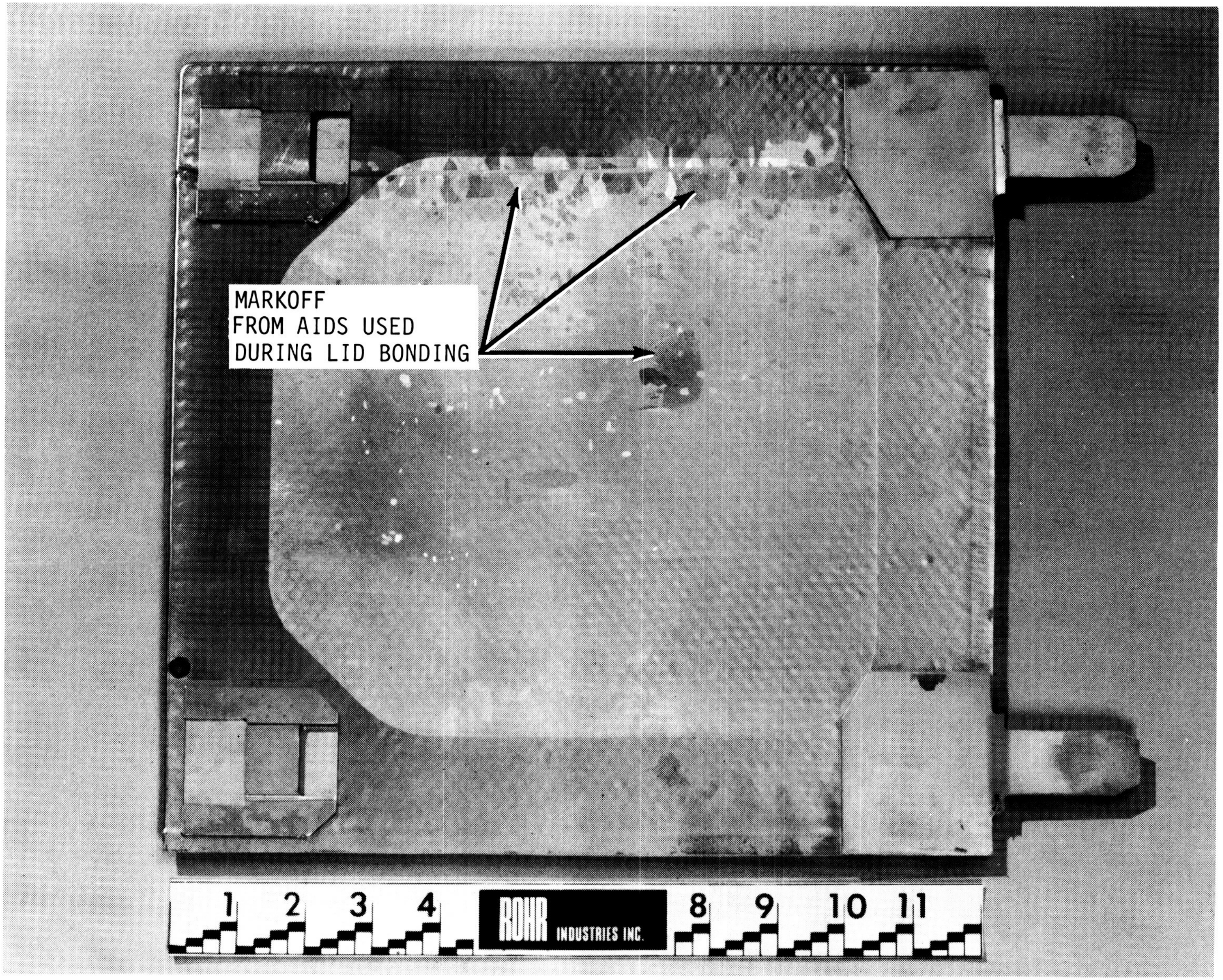


Figure 11. Bottom of Titanium Subassembly after LID Bonding

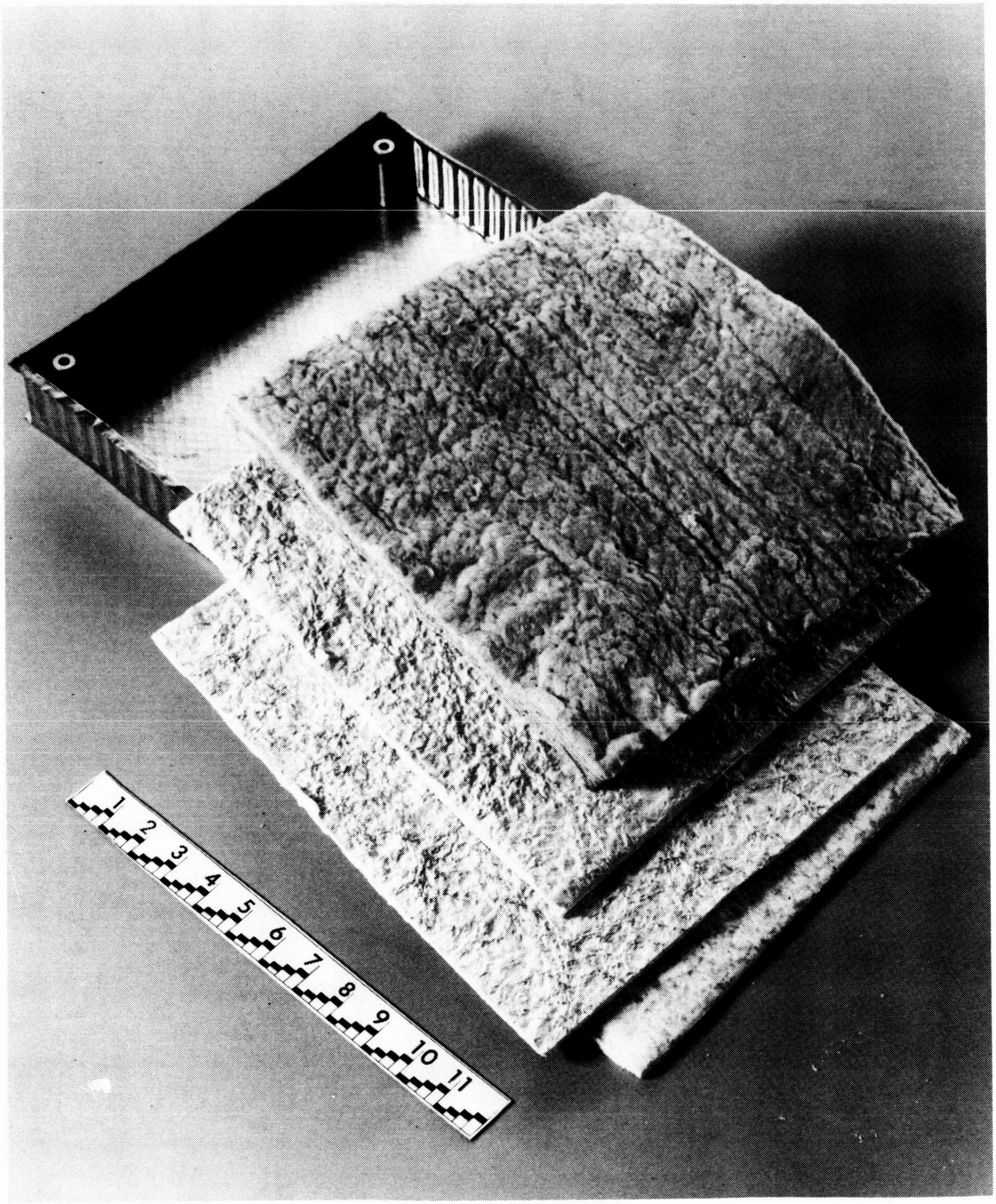


Figure 12. Pre-cut Q-Fiber Felt and DYNAFLEX Ready to be Installed into the INCONEL 617 Subassembly

Figure 13. INCONEL 617 Subassembly with DYNAFLEX and Q-FIBER FELT Installed

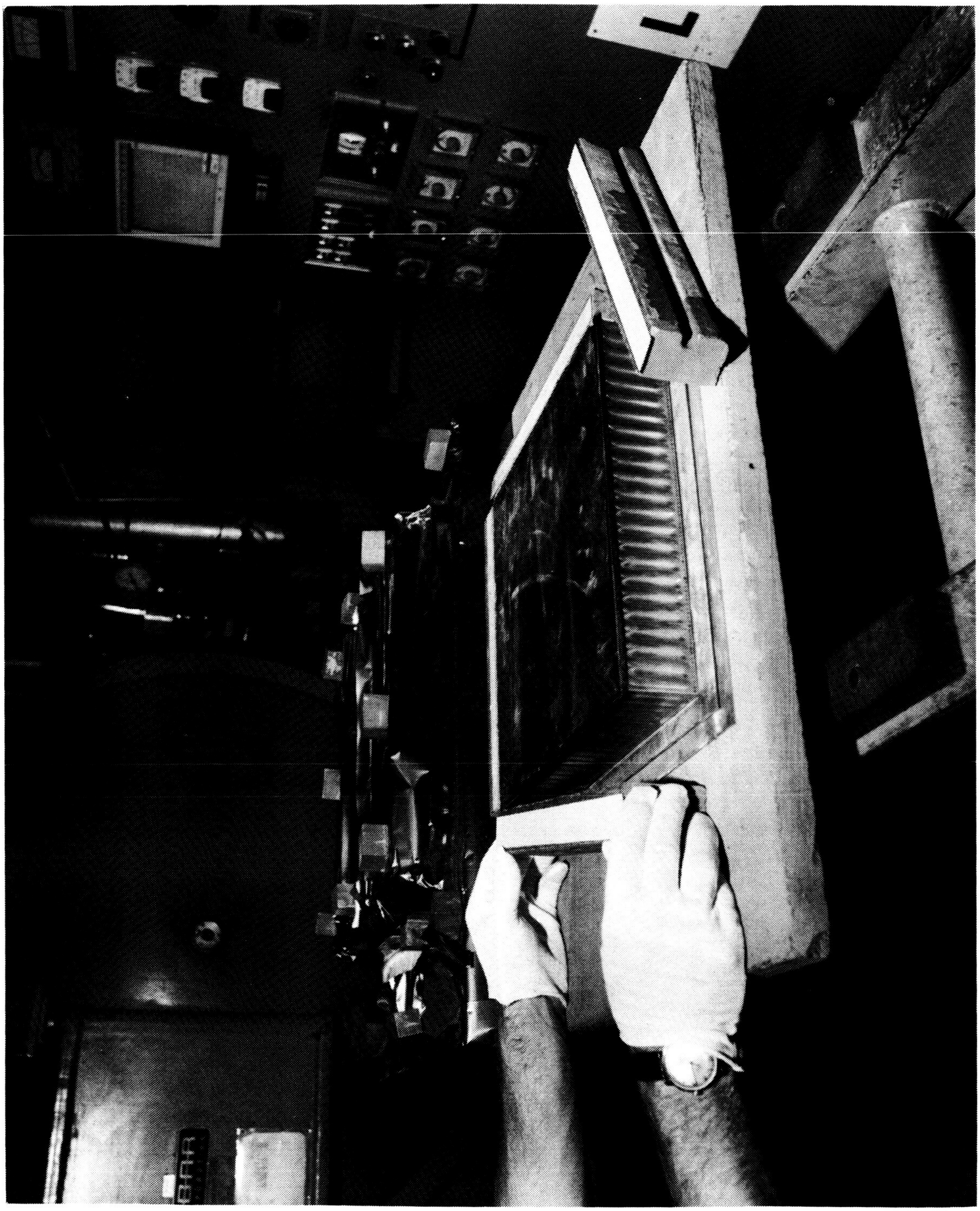


Figure 14. Bi-Metal Assembly Being Laid up for LID Bonding

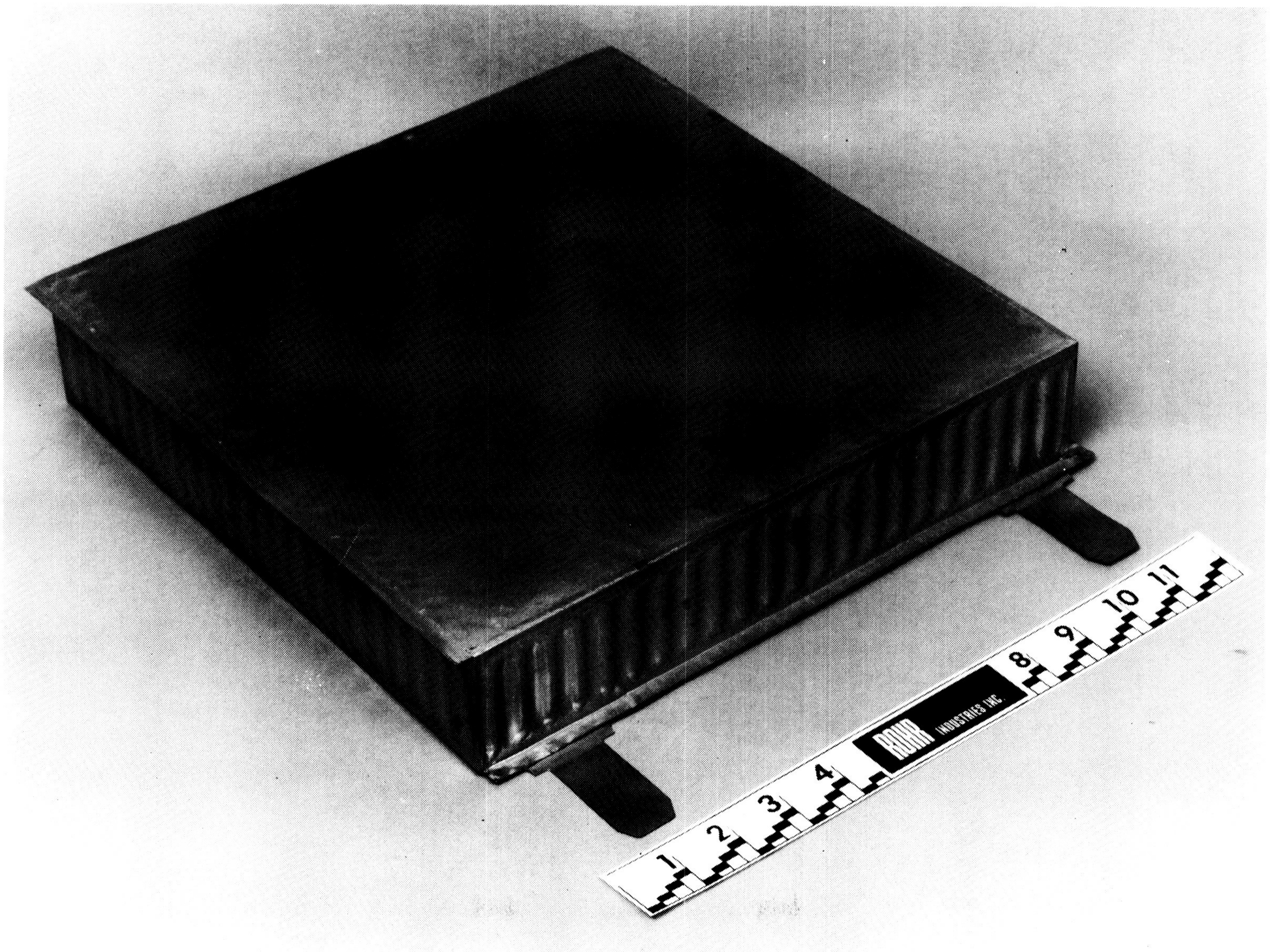


Figure 15. Top of Completed Bi-Metal Panel

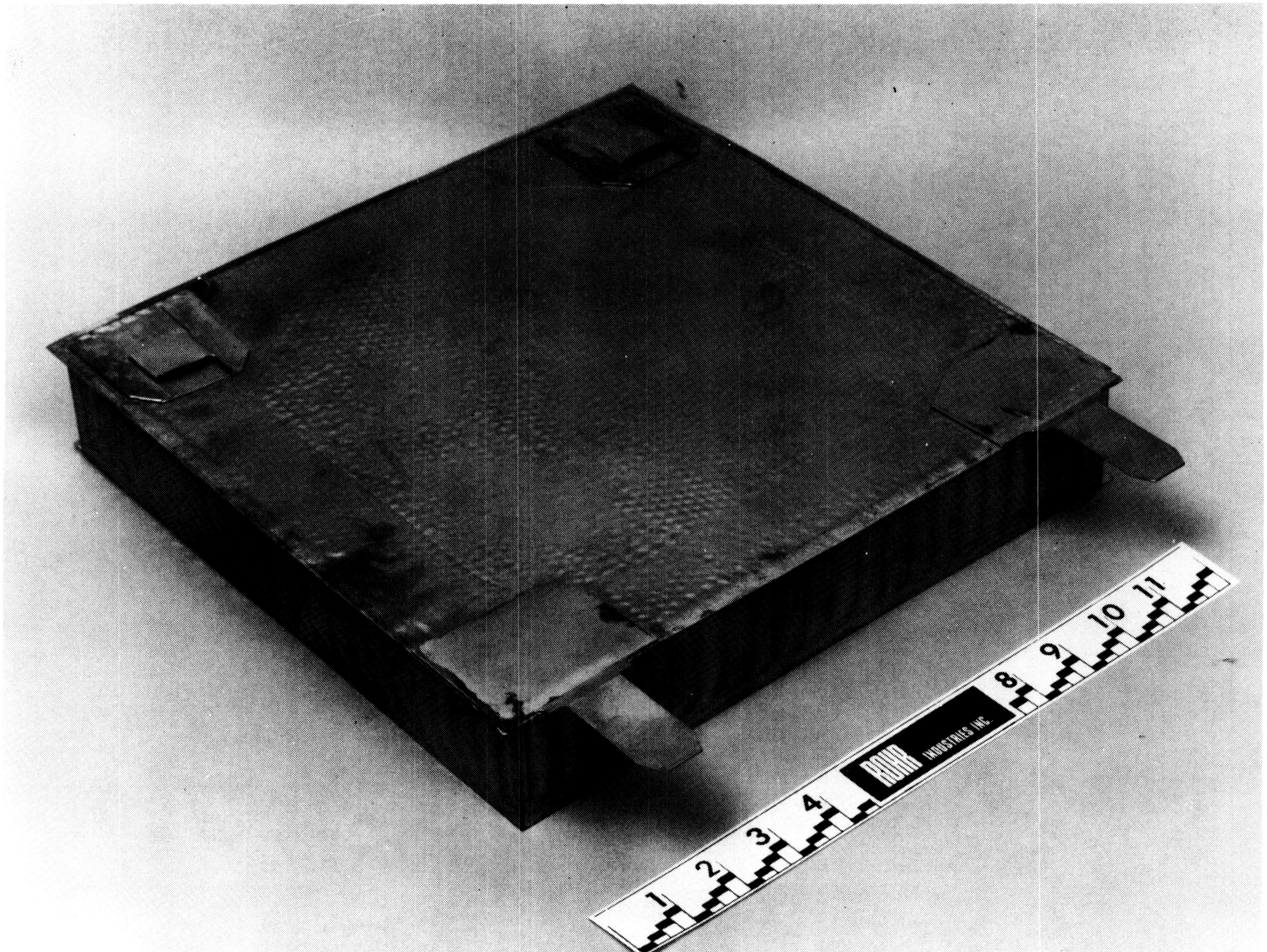
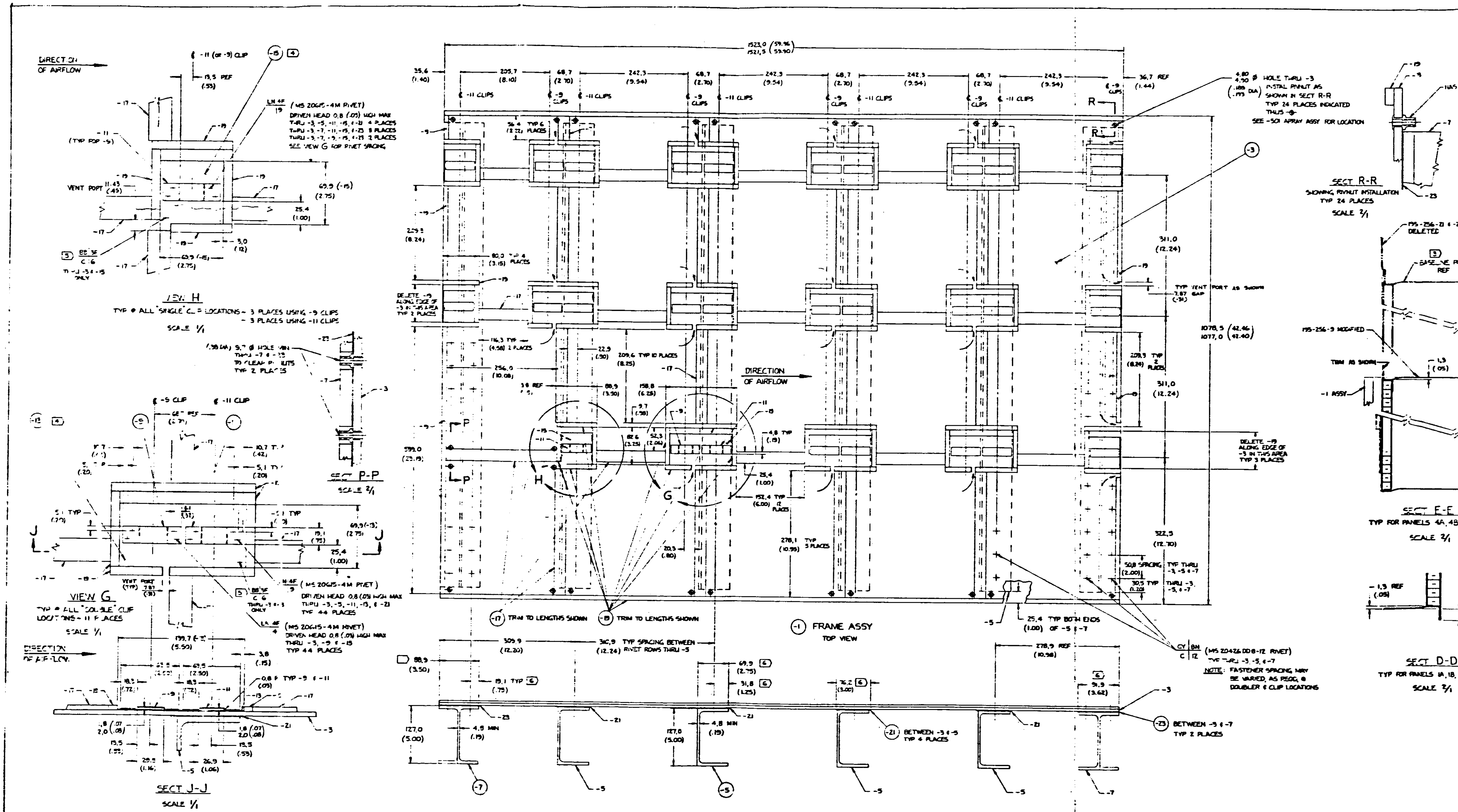


Figure 16. Bottom of Completed Bi-Metal Panel

Figure 17. Superalloy--Titanium--Silica Sandwich Panel--20-Panel Array



DIRECTION OF AIRFLOW
VIEW H
TYP @ ALL "SINGLE" CLIP LOCATIONS ~ 3 PLACES USING -9 CLIPS
~ 3 PLACES USING -11 CLIPS
SCALE 1/1
SECT P-P
SCALE 2/1
VIEW G
TYP @ ALL "DOUBLE" CLIP LOCATIONS ~ 11 PLACES
SCALE 1/1
SECT J-J
SCALE 1/1
(-1) FRAME ASSY
TOP VIEW
(-17) TRIM TO LENGTHS SHOWN
(-19) TRIM TO LENGTHS SHOWN
DIRECTION OF AIRFLOW
SECT R-R
SHOWING RIVNUT INSTALLATION
TYP 24 PLACES
SCALE 2/1
SECT E-E
TYP FOR PANELS 4A, 4B
SCALE 2/1
SECT D-D
TYP FOR PANELS 1A, 1B
SCALE 2/1
NOTE: FASTENER SPACING MAY BE VARIED, AS REQD, @ DOUBLER & CLIP LOCATIONS
(-21) BETWEEN -3 & -5 TYP 4 PLACES
(-23) BETWEEN -5 & -7 TYP 2 PLACES

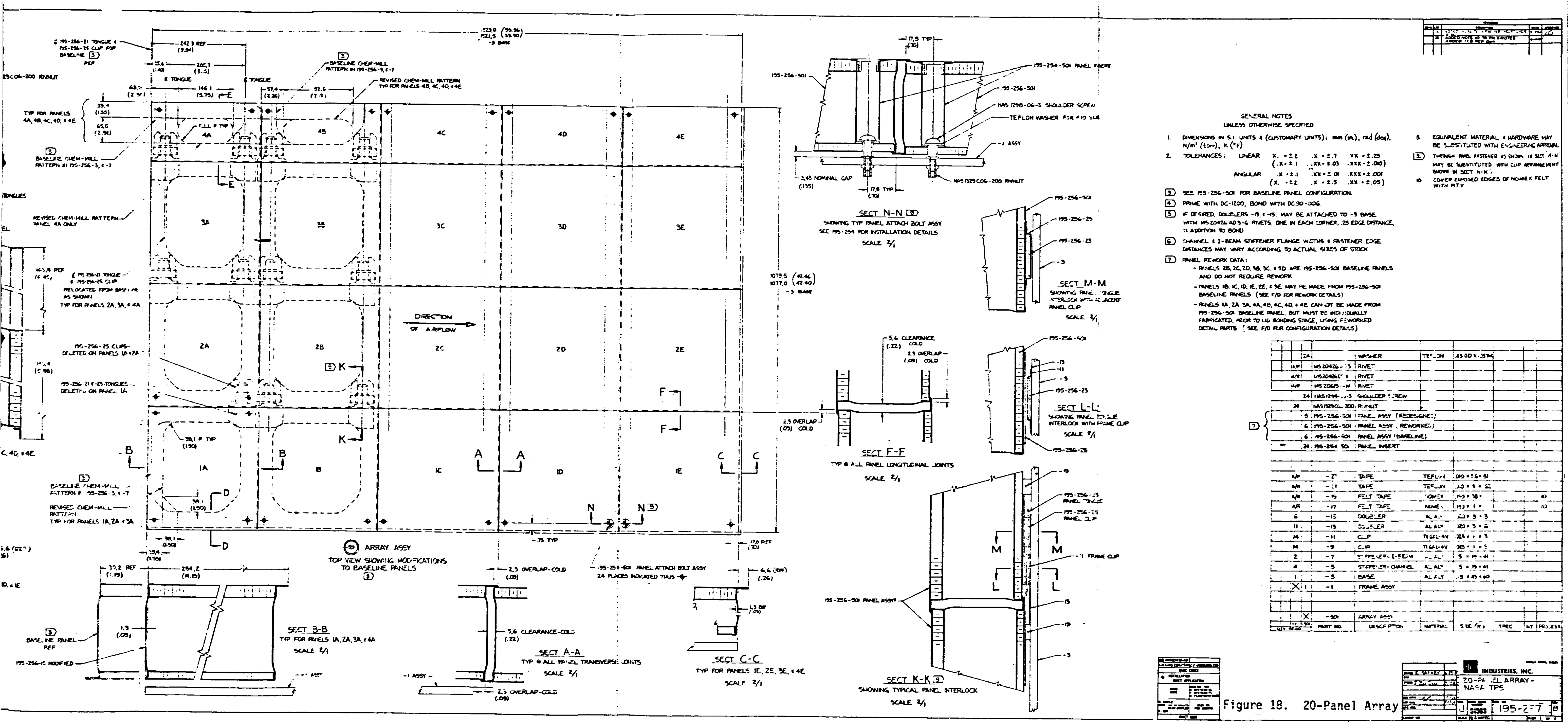


Figure 18. 20-Panel Array

2

Figure 19. Six Titanium Subassemblies being Removed from Vacuum Furnace after LID Bonding

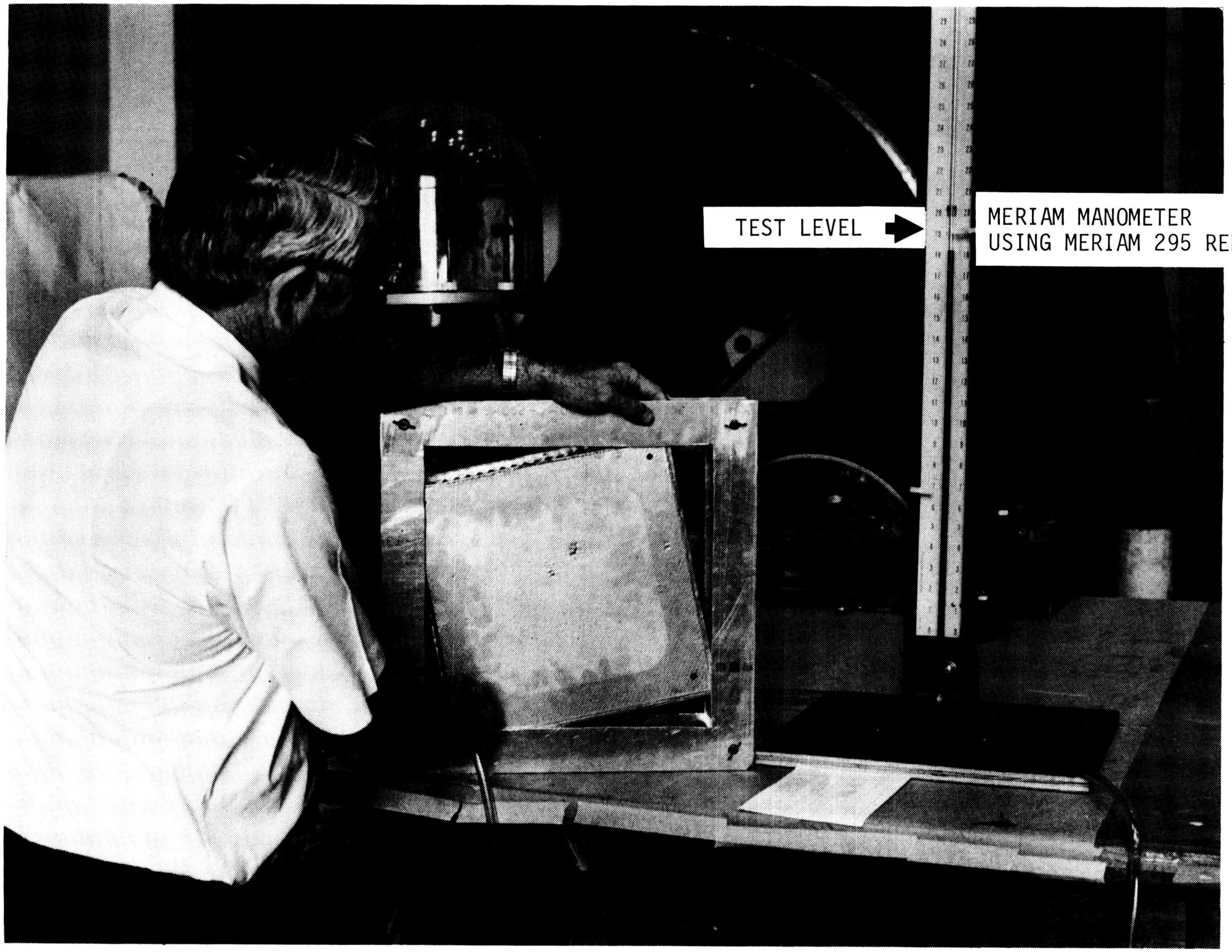


Figure 20. Pressure Testing Superalloy Sandwich Panel

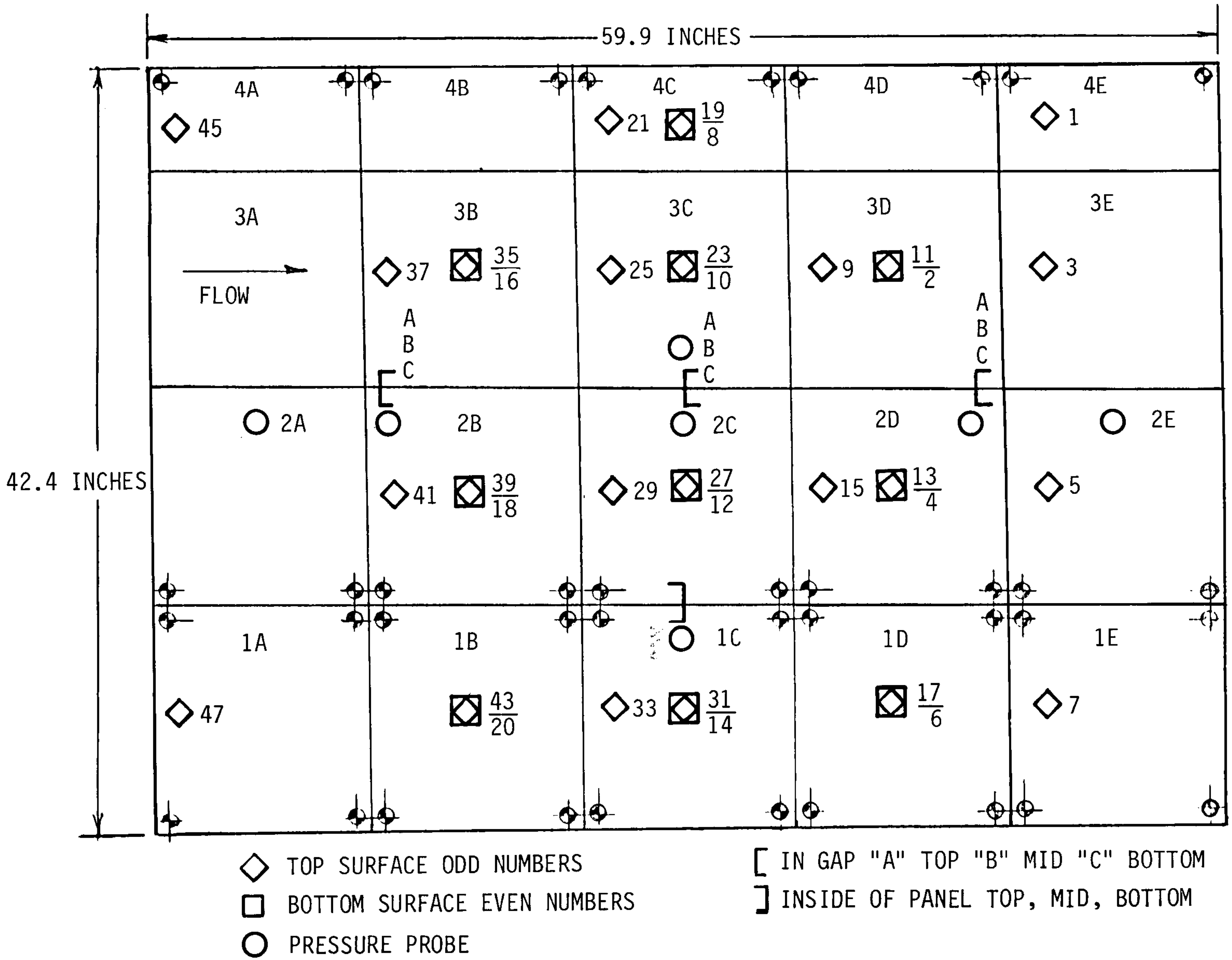


Figure 21. Thermocouple Layout by Panel Serial Number

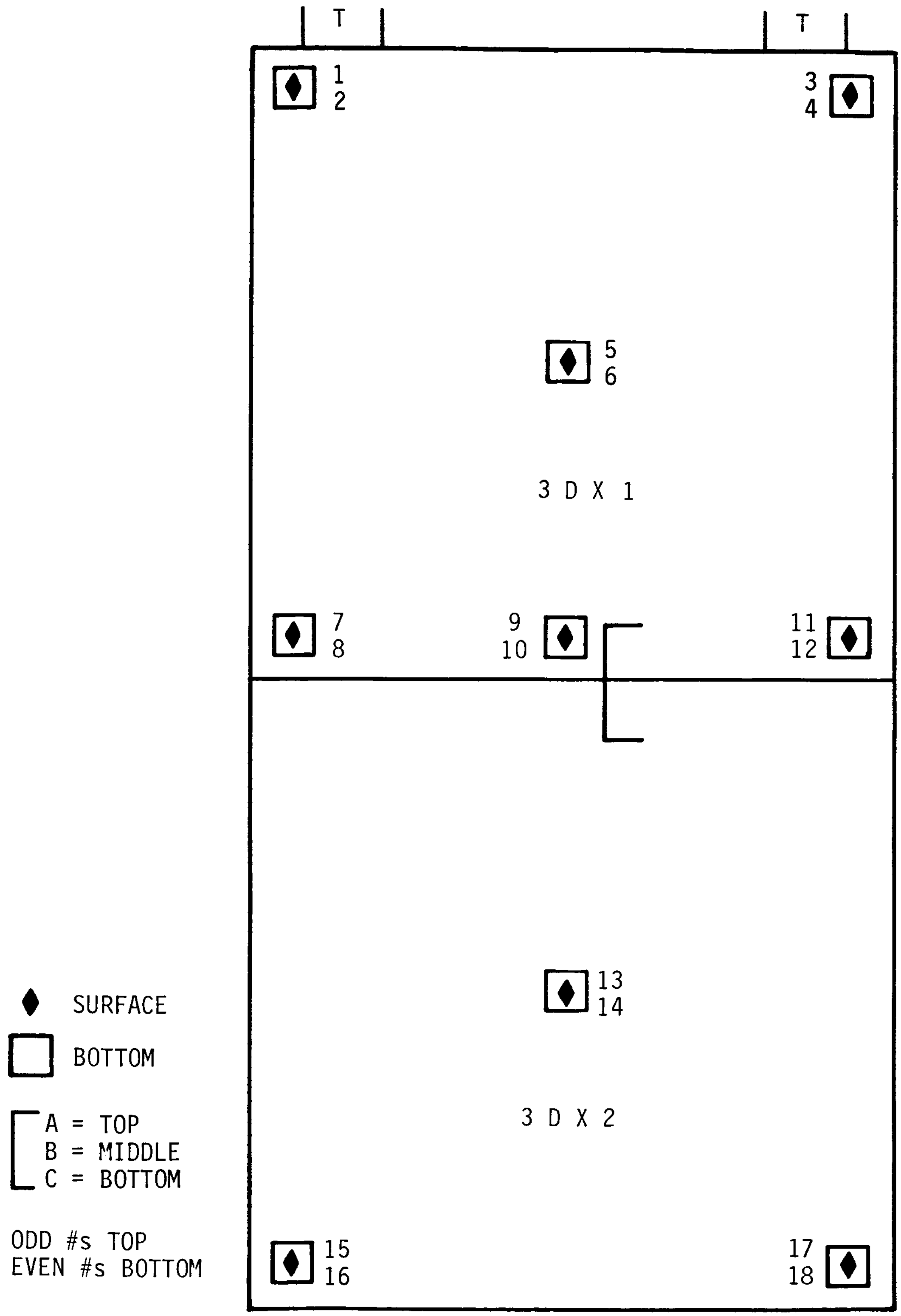


Figure 22. Thermocouple Layout for 2-Panel Array

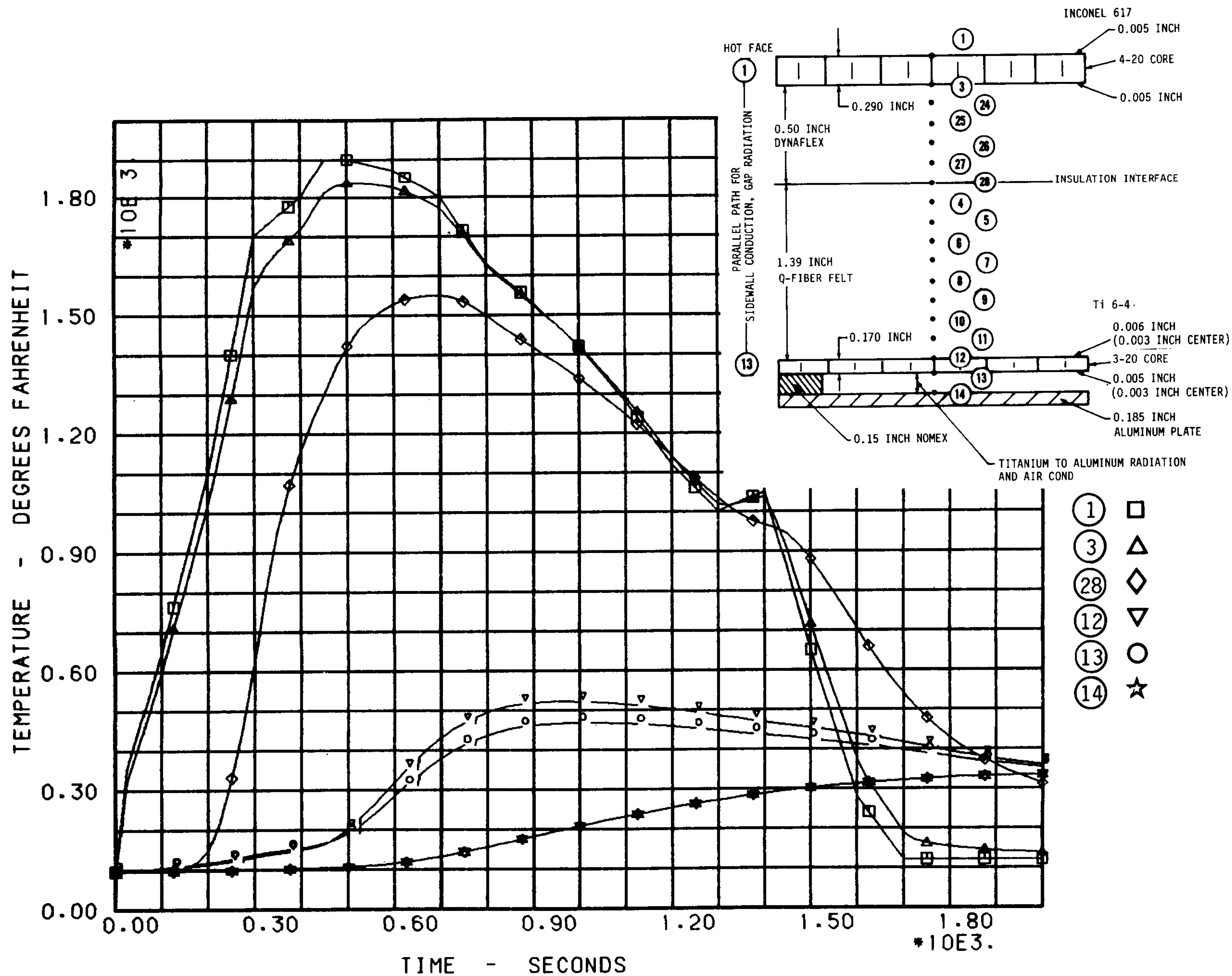


Figure 23. Thermal Math Model, Transient Analysis

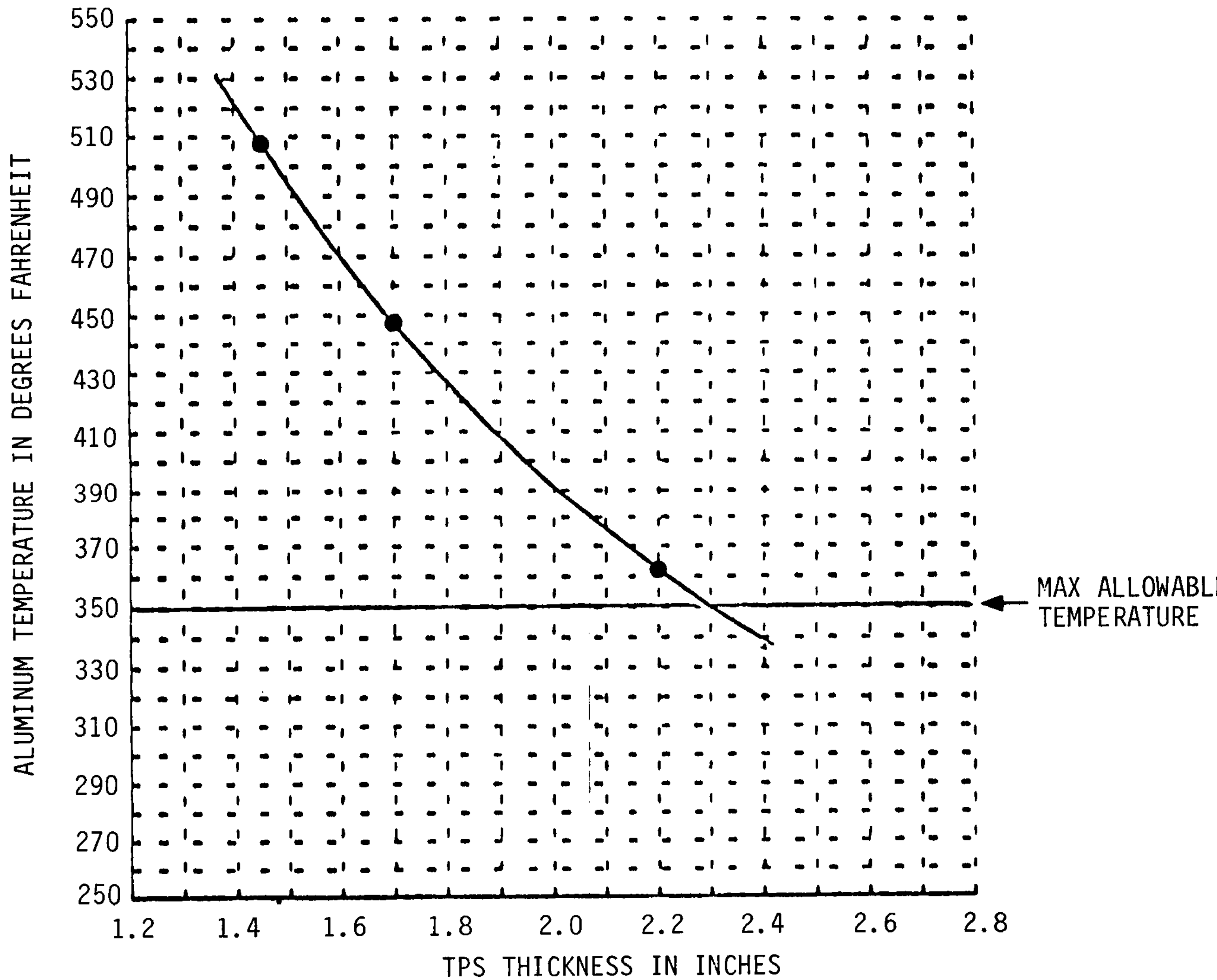


Figure 24. B.P. 1300 Aluminum Temperature Versus TPS Thickness
NOMEX Thickness is Not Included

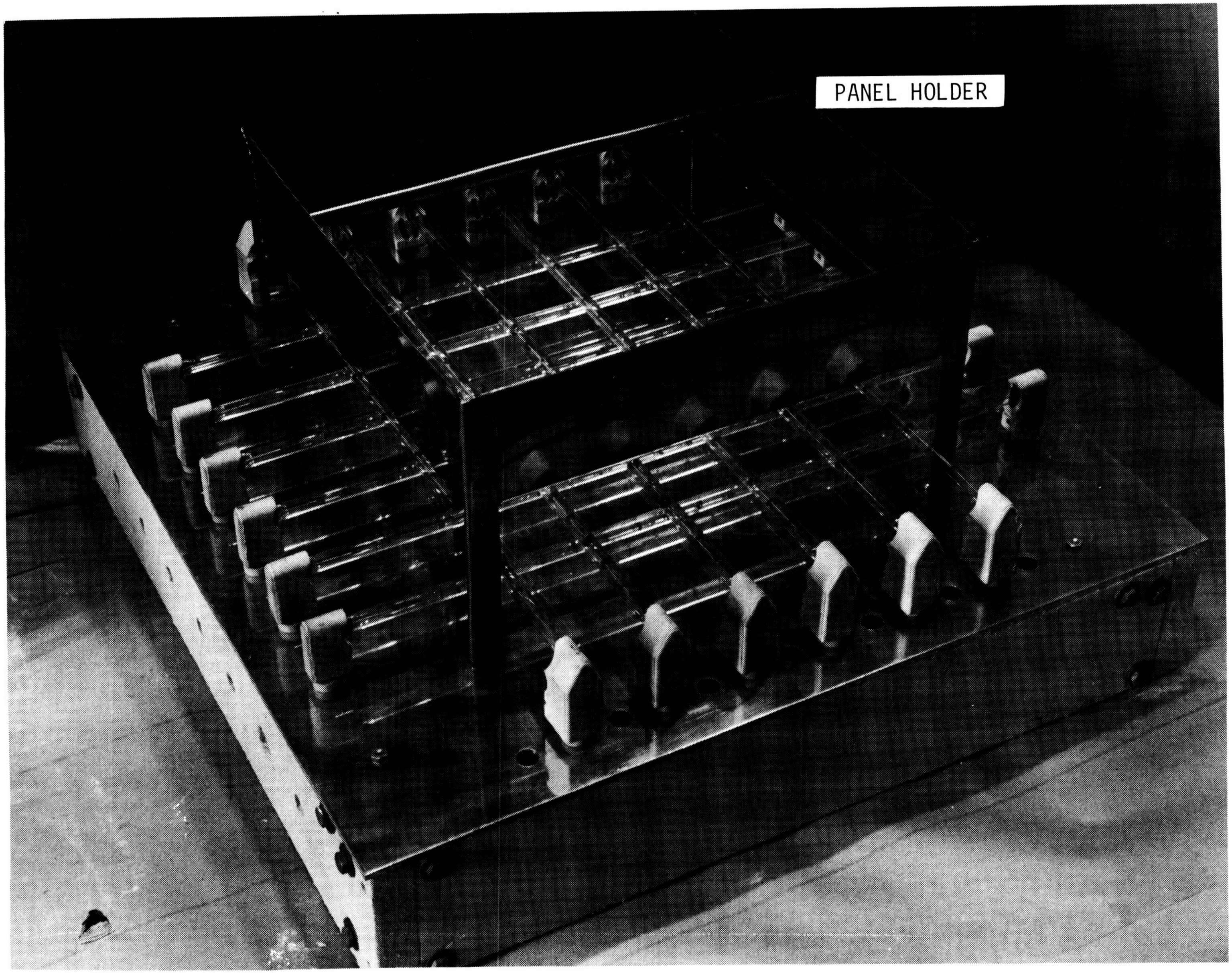


Figure 25. Guarded Hot Plate with Zoned Heating

Figure 26. Guarded Hot Plate with Thermac Controller

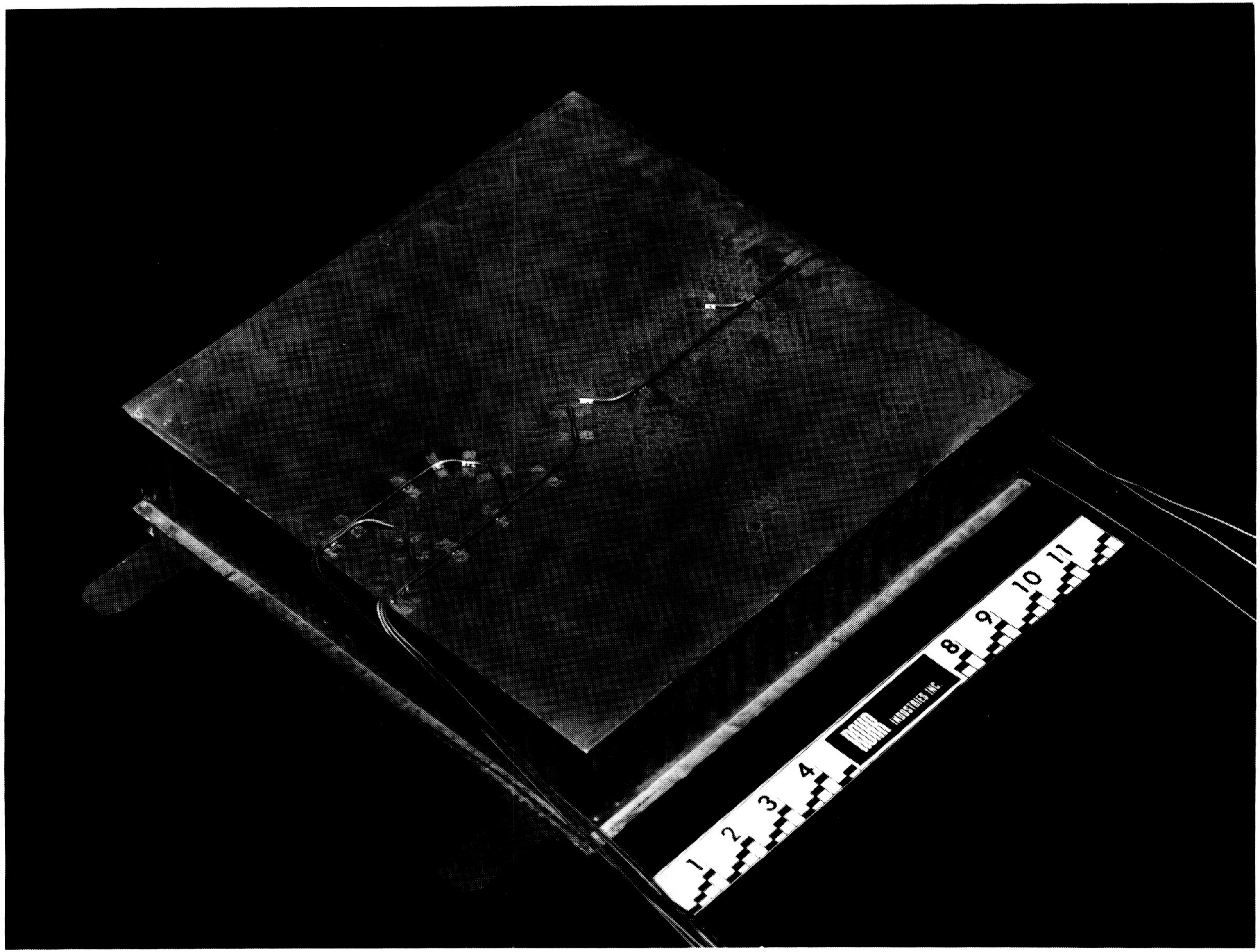


Figure 27. Superalloy Panel with Thermocouples Installed.

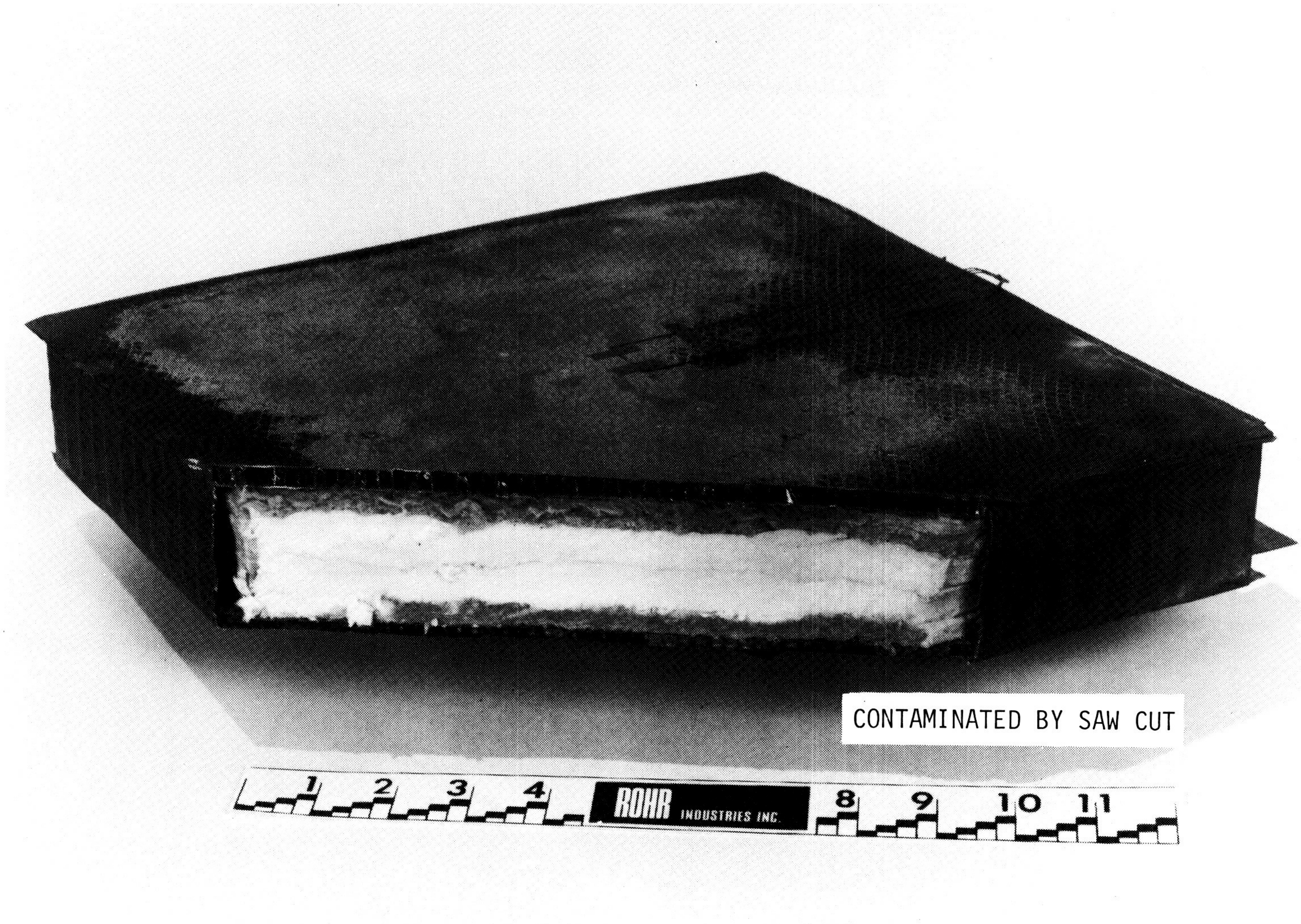


Figure 28. Superalloy Panel Section after Thermal Conductivity Tests

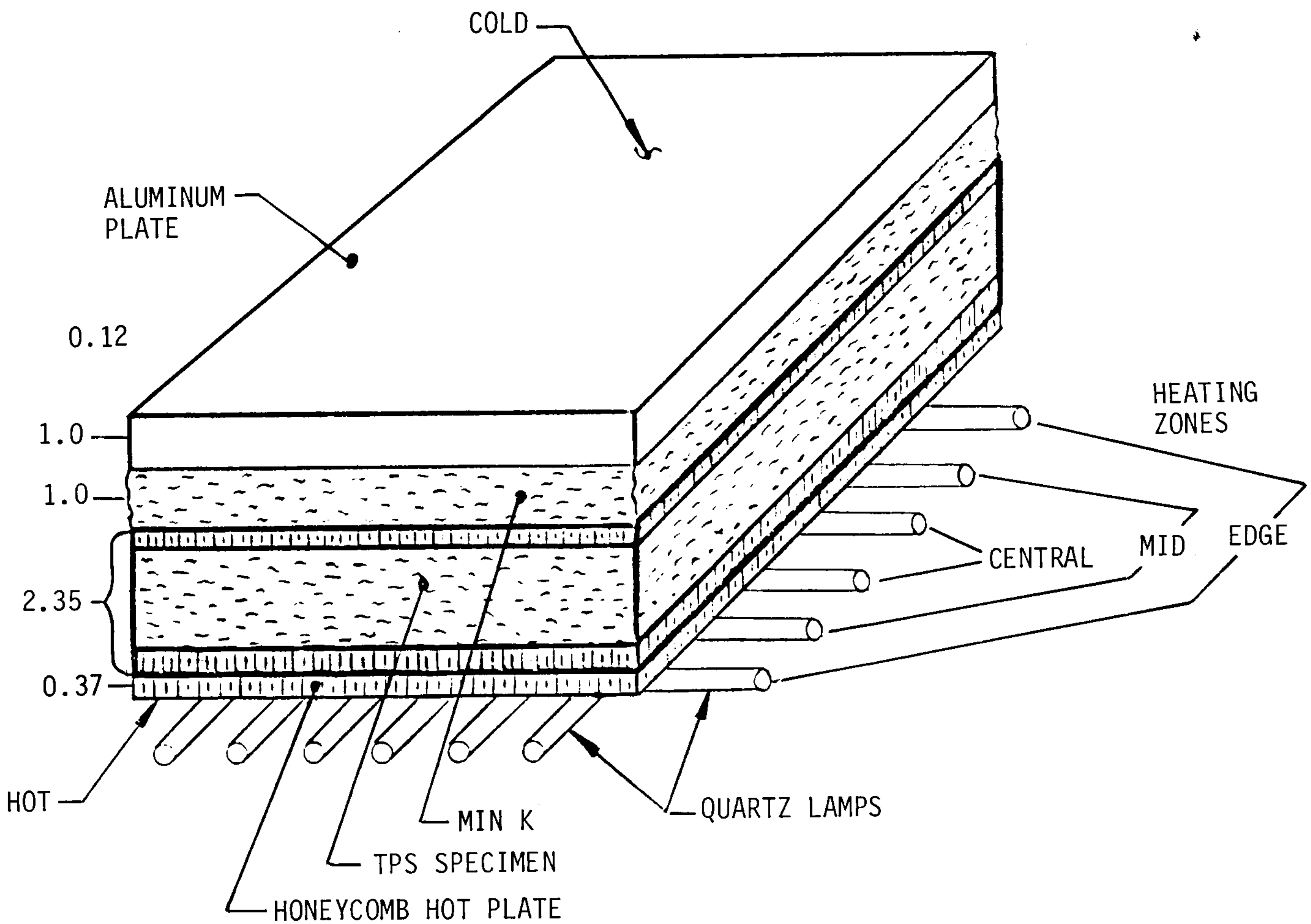


Figure 29. Thermal Conductivity Test Setup

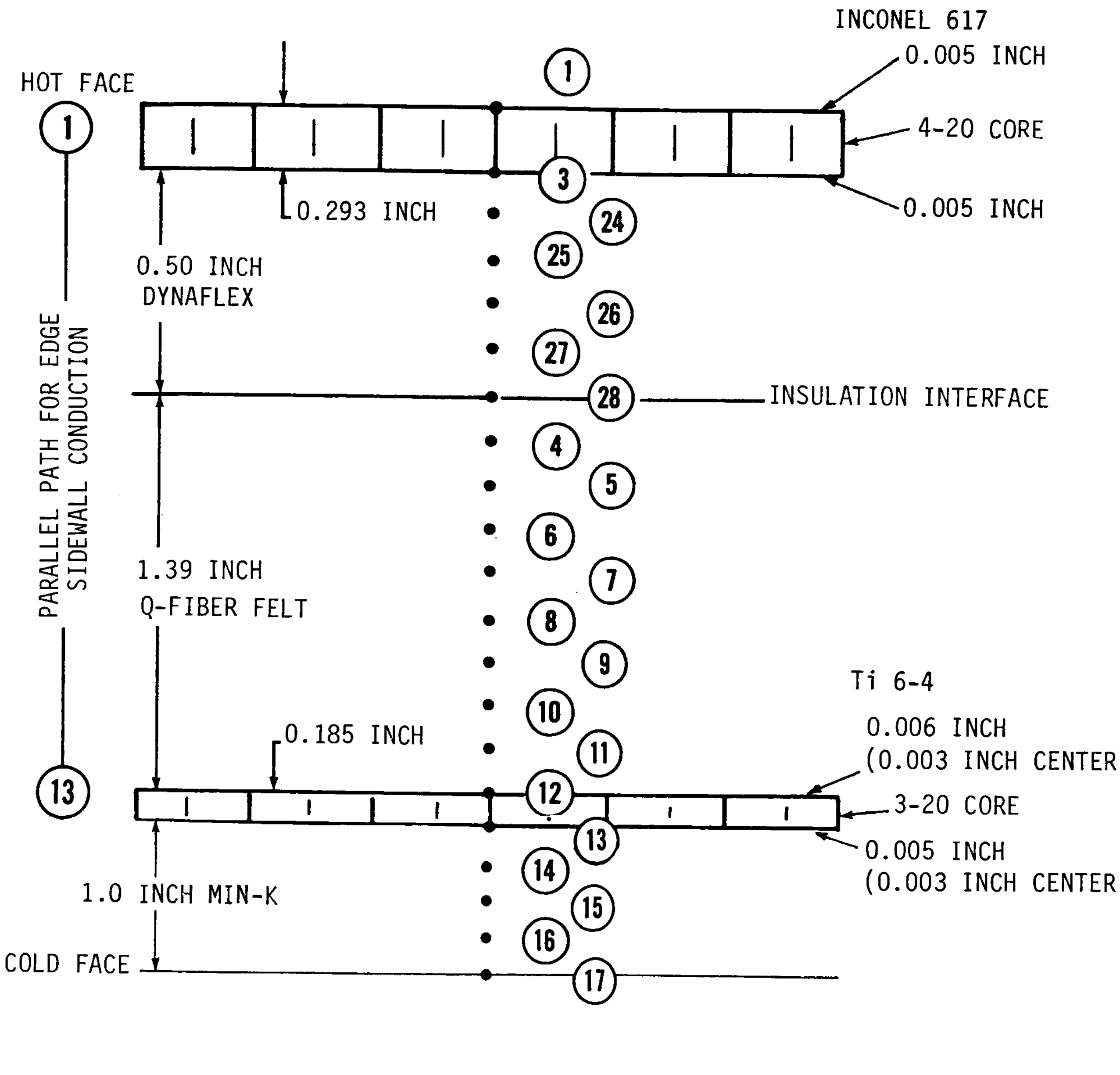


Figure 30. Thermal Math Model, Steady State Analysis

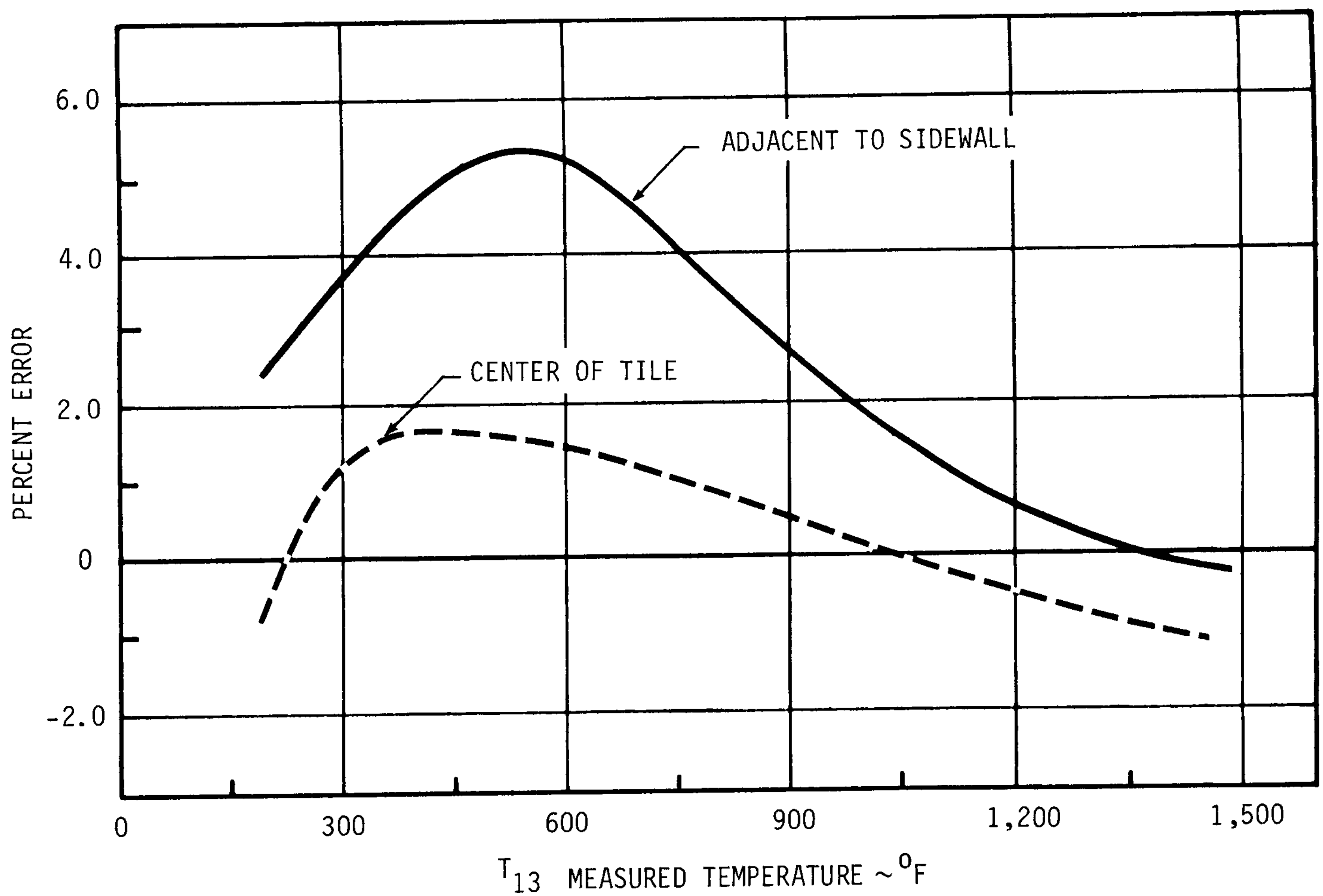


Figure 31. Percent Error Versus Measured Temperature

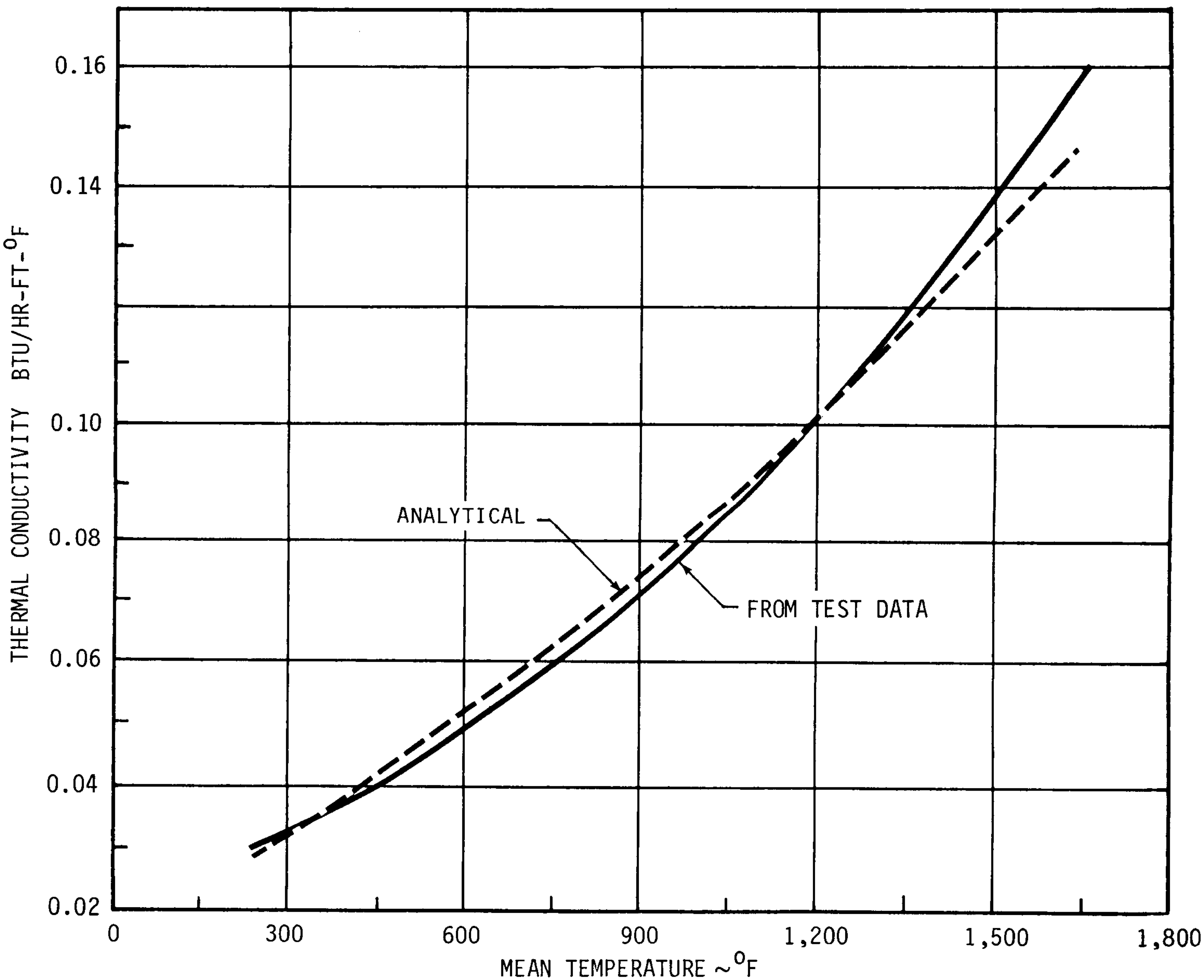
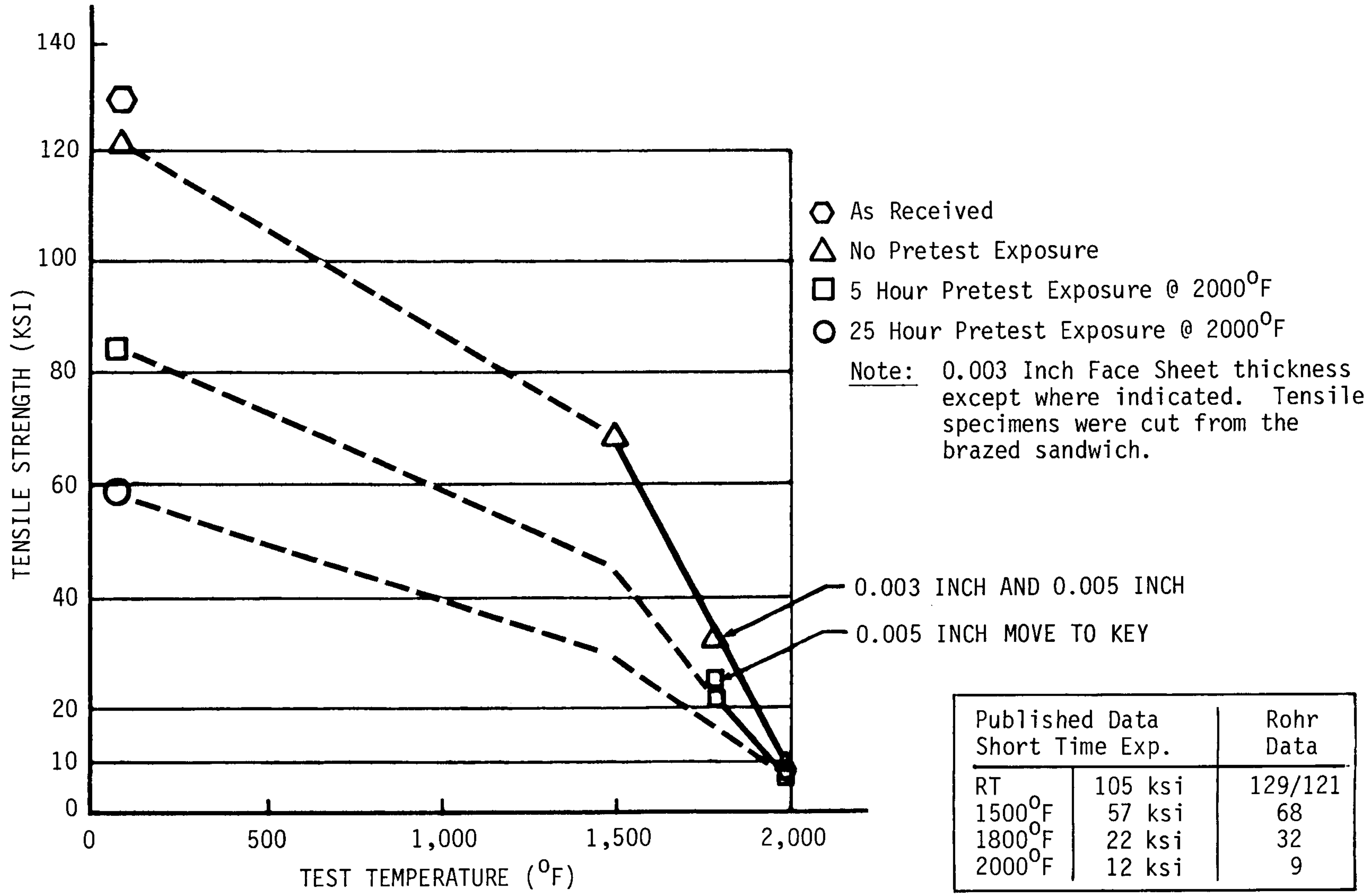
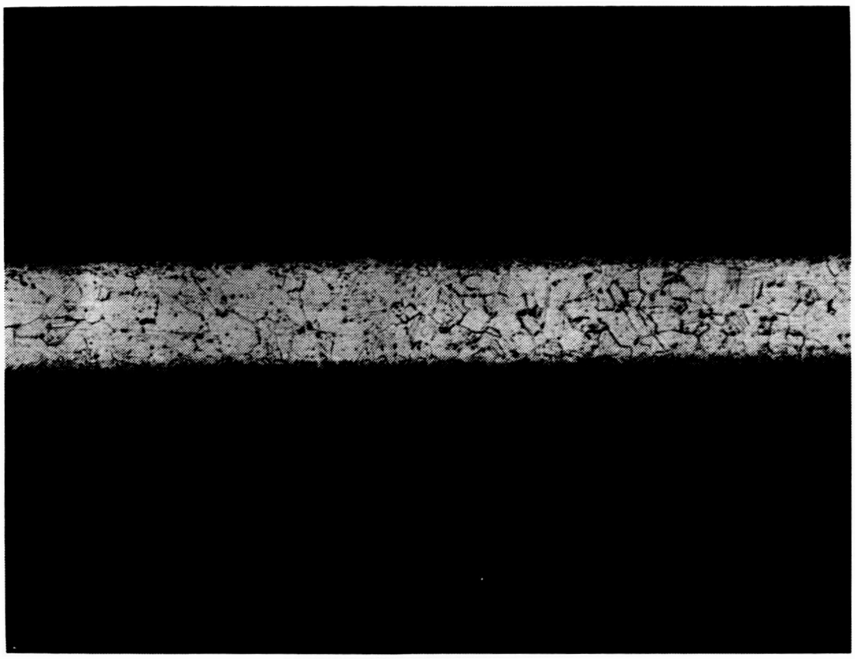


Figure 32. Effective Thermal Conductivity as a Function of Temperature



Published Data Short Time Exp.		Rohr Data
RT	105 ksi	129/121
1500°F	57 ksi	68
1800°F	22 ksi	32
2000°F	12 ksi	9

Figure 33. Face Sheet Ultimate Tensile Strength Versus Test Temperature INCONEL 617

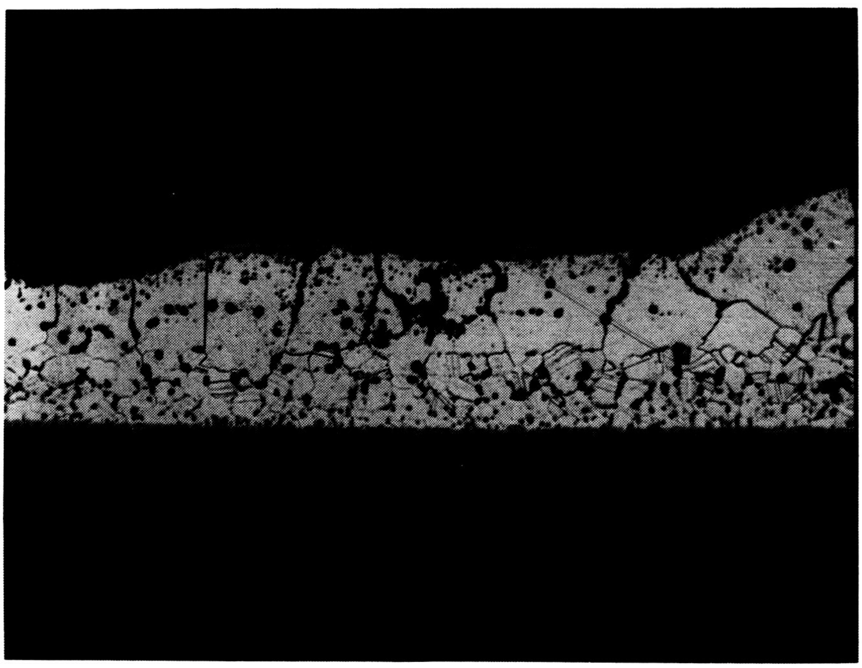


81-1036-5 200X KALLINGS ETCH

Figure 34. Photomicrograph of As-Received Foil

81-1036-1 200X KALLINGS ETCH

Figure 35. Photomicrograph of Brazed Foil after 5 Hours of Exposure to $2000^{\circ}F$



81-1036-4 200X KALLINGS ETCH

Figure 36. Photomicrograph of Brazed Foil after 25 Hours of Exposure to 2000°F

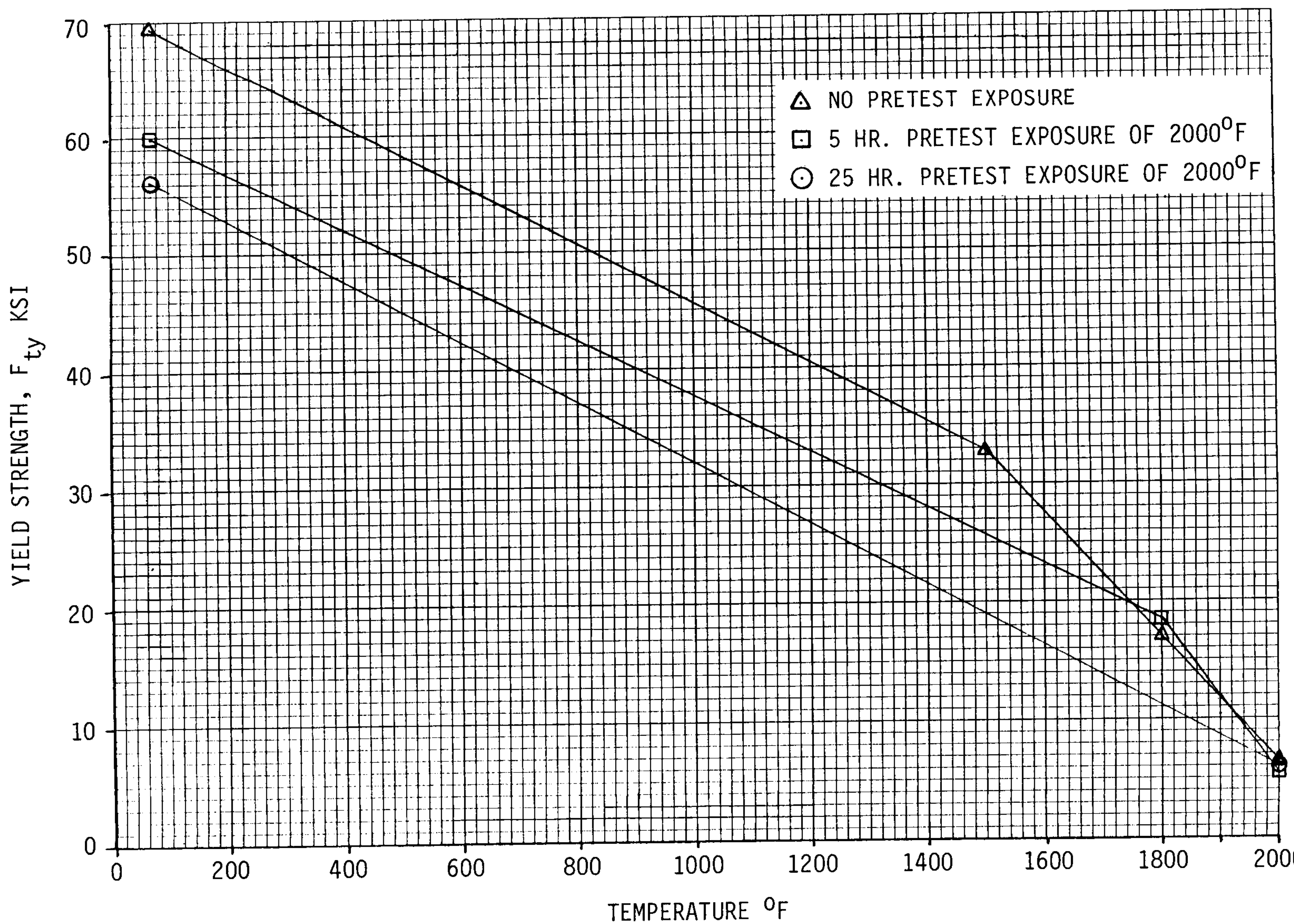


Figure 37. Tensile Yield Strength of Inco 617 Face Sheets - Brazed

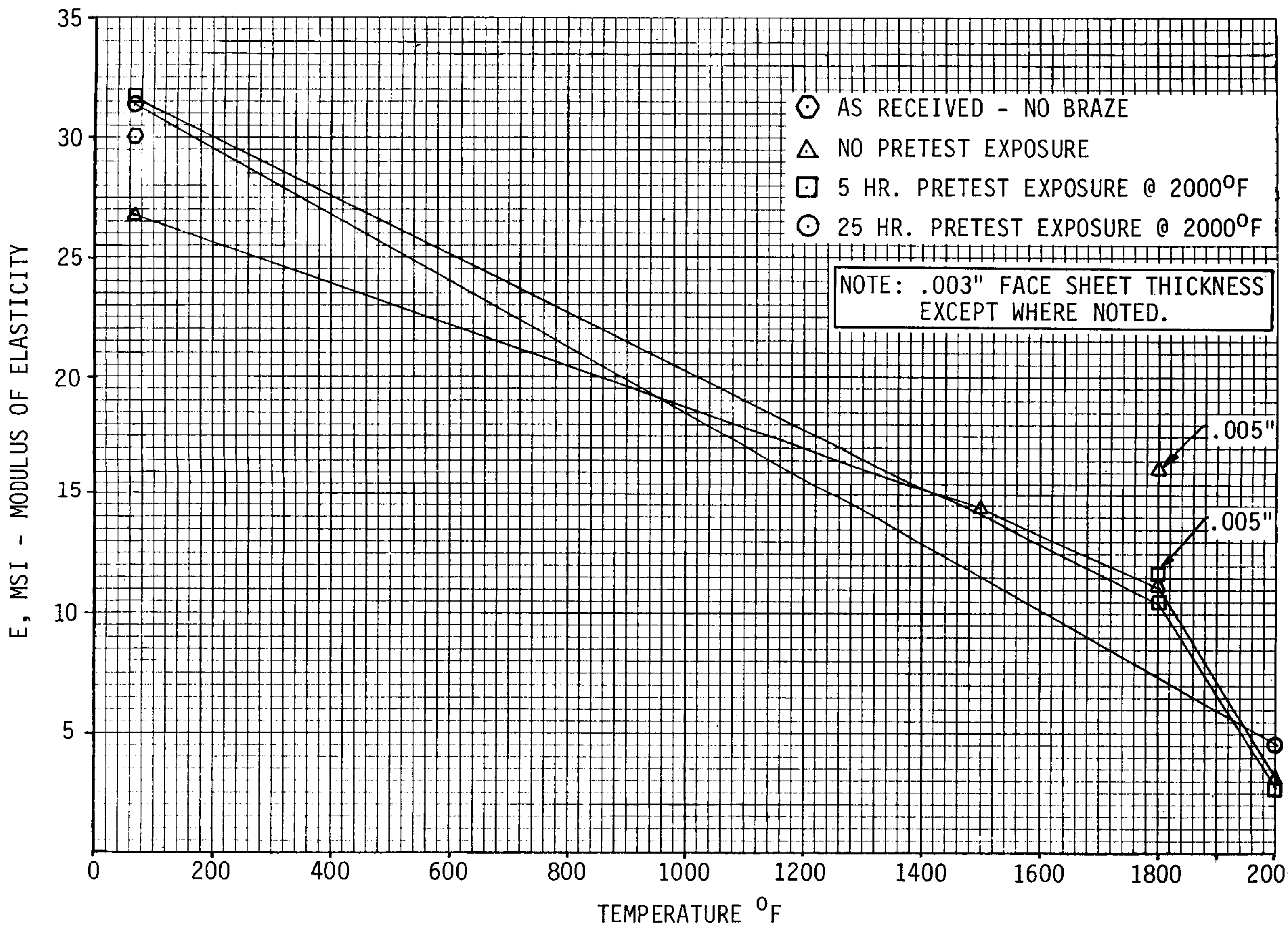


Figure 38. Modulus of Elasticity, E, of Inco 617 Face Sheets - Brazed

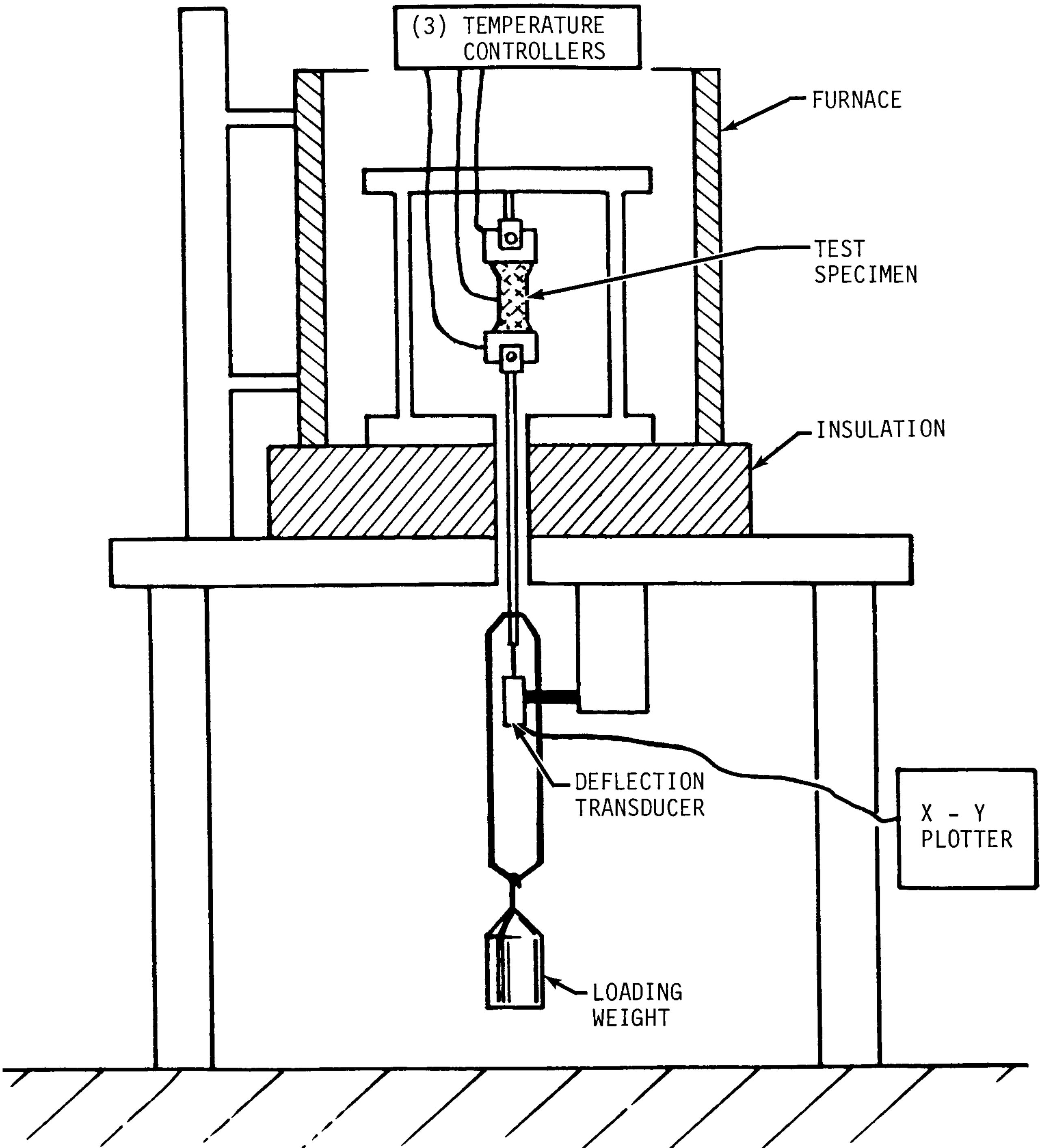


Figure 39. Schematic of Creep Test Setup

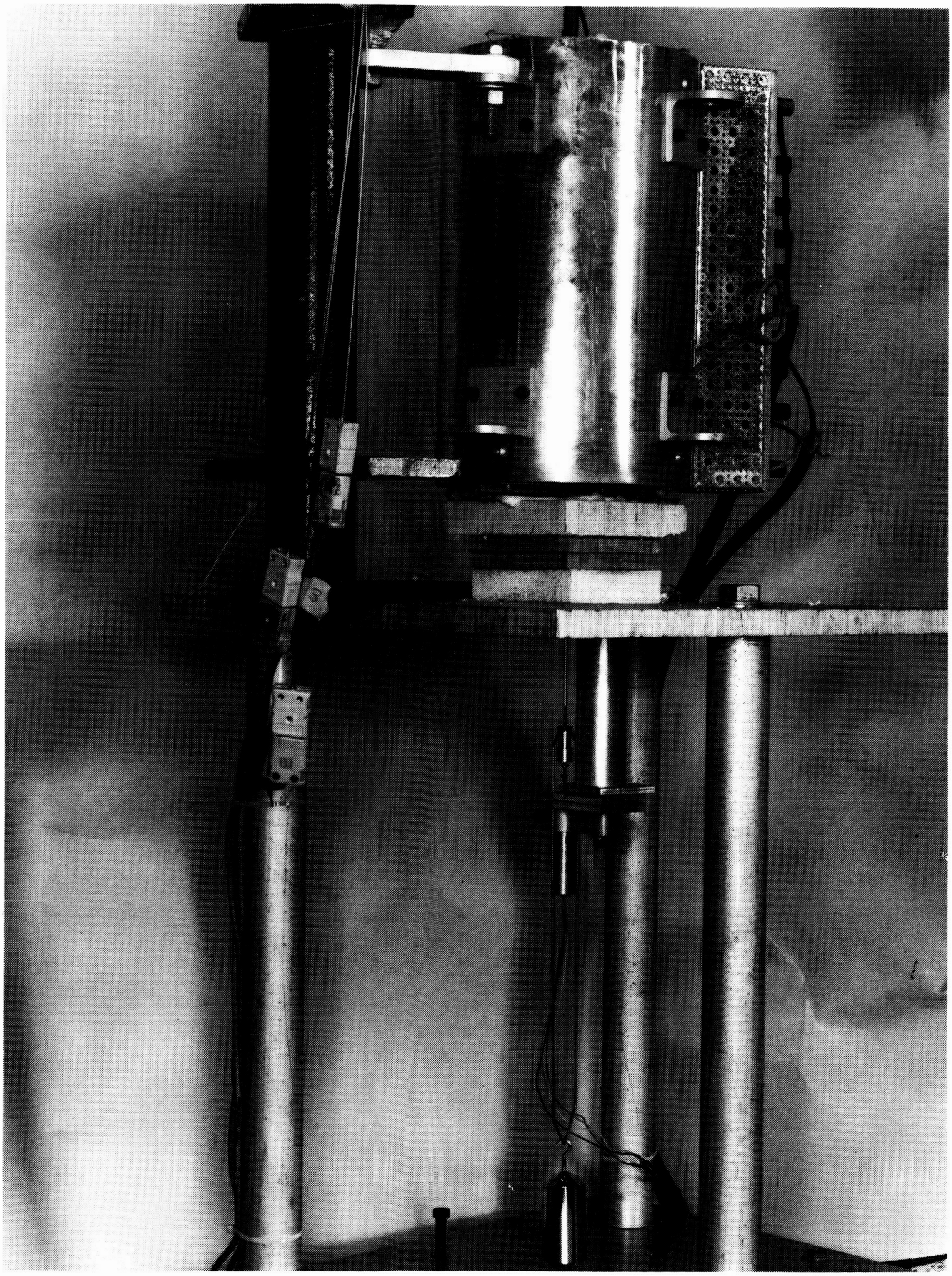


Figure 40. Overall View of Creep Test Setup

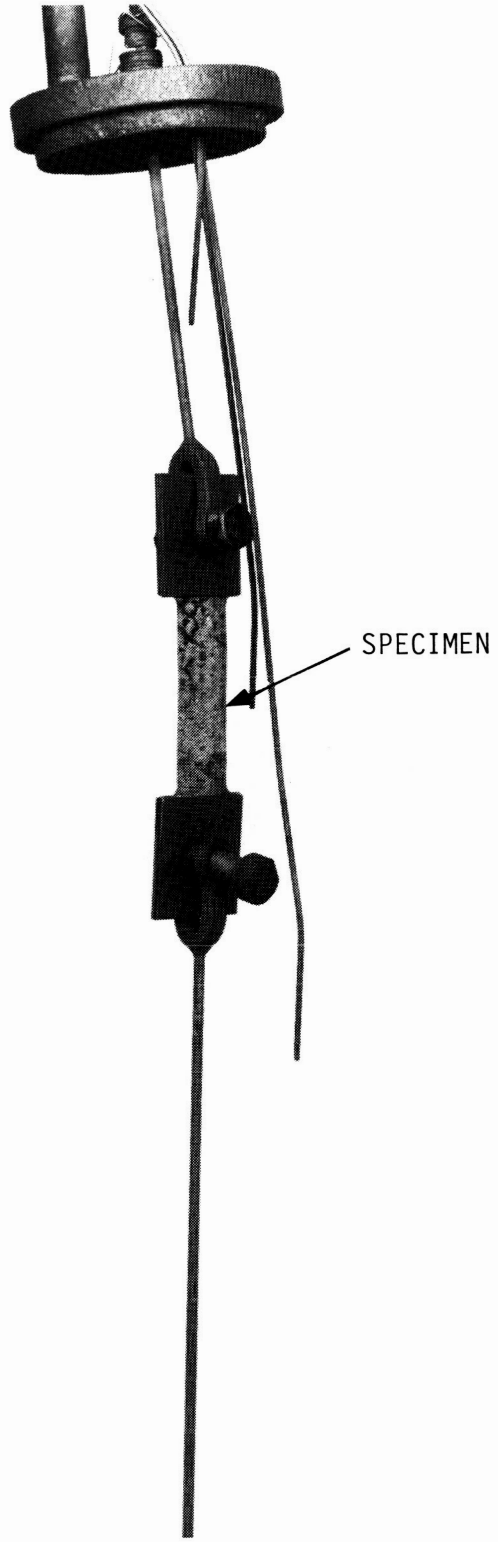


Figure 41. Large Creep Test Specimen

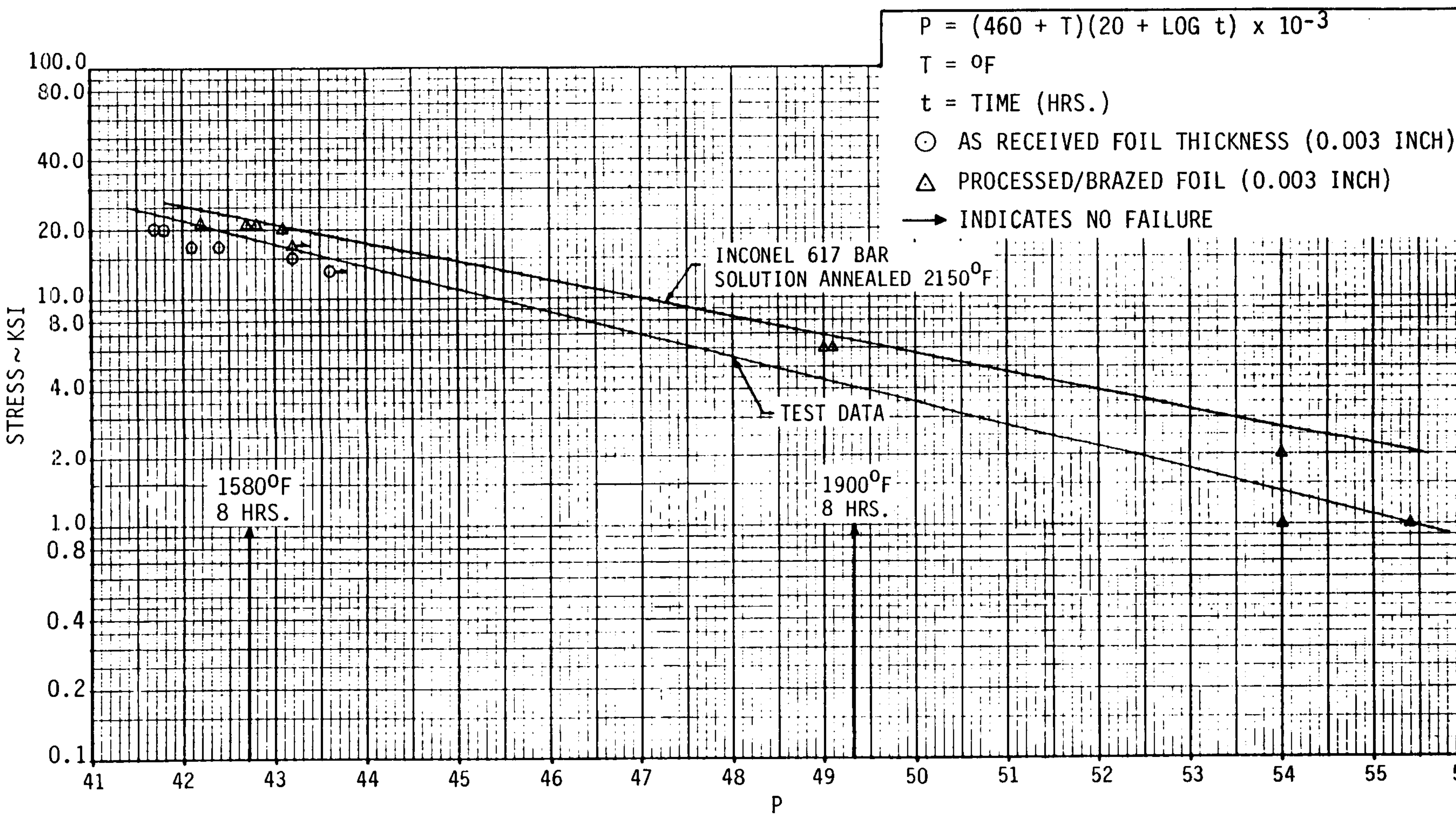


Figure 42. INCONEL 617 Creep Rupture Larson--Miller Plot

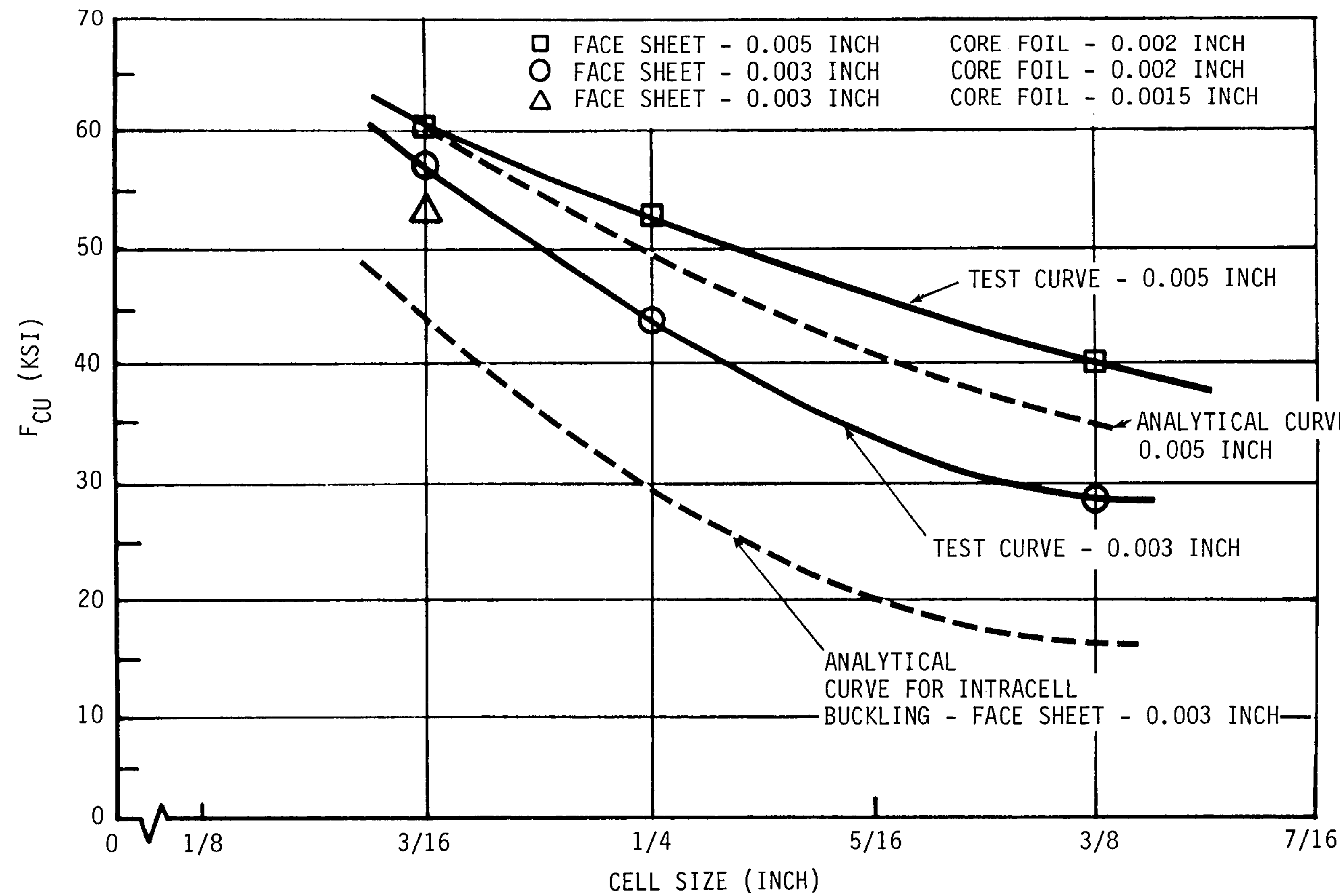


Figure 43. Edgewise Compression Strength Versus Cell Size INCONEL 617 (Room-Temp) 7.4.1 (see table 17)

Figure 44. Room Temperature Flatwise Tension Test Setup

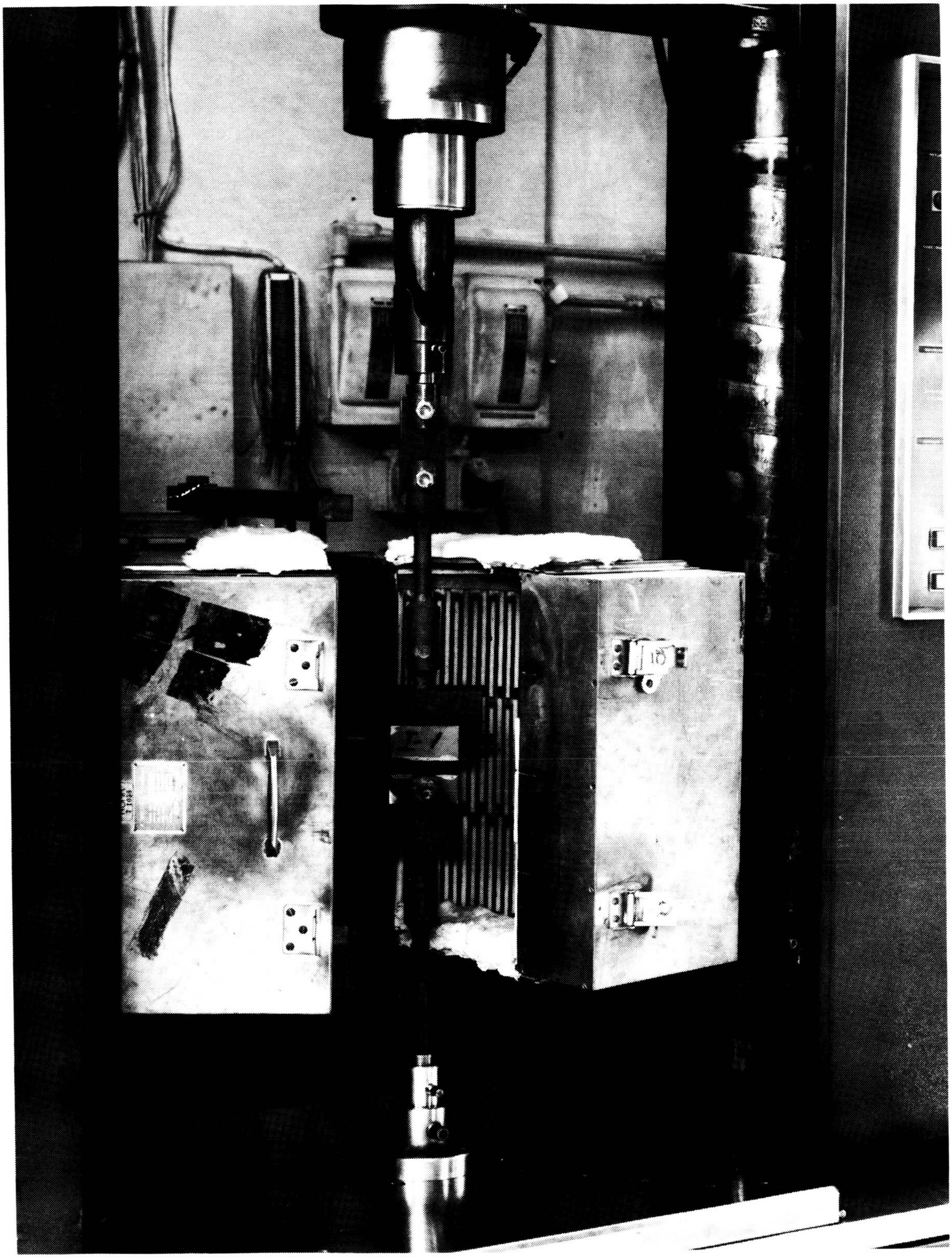


Figure 45. Elevated Temperature Flatwise Tension Test Setup

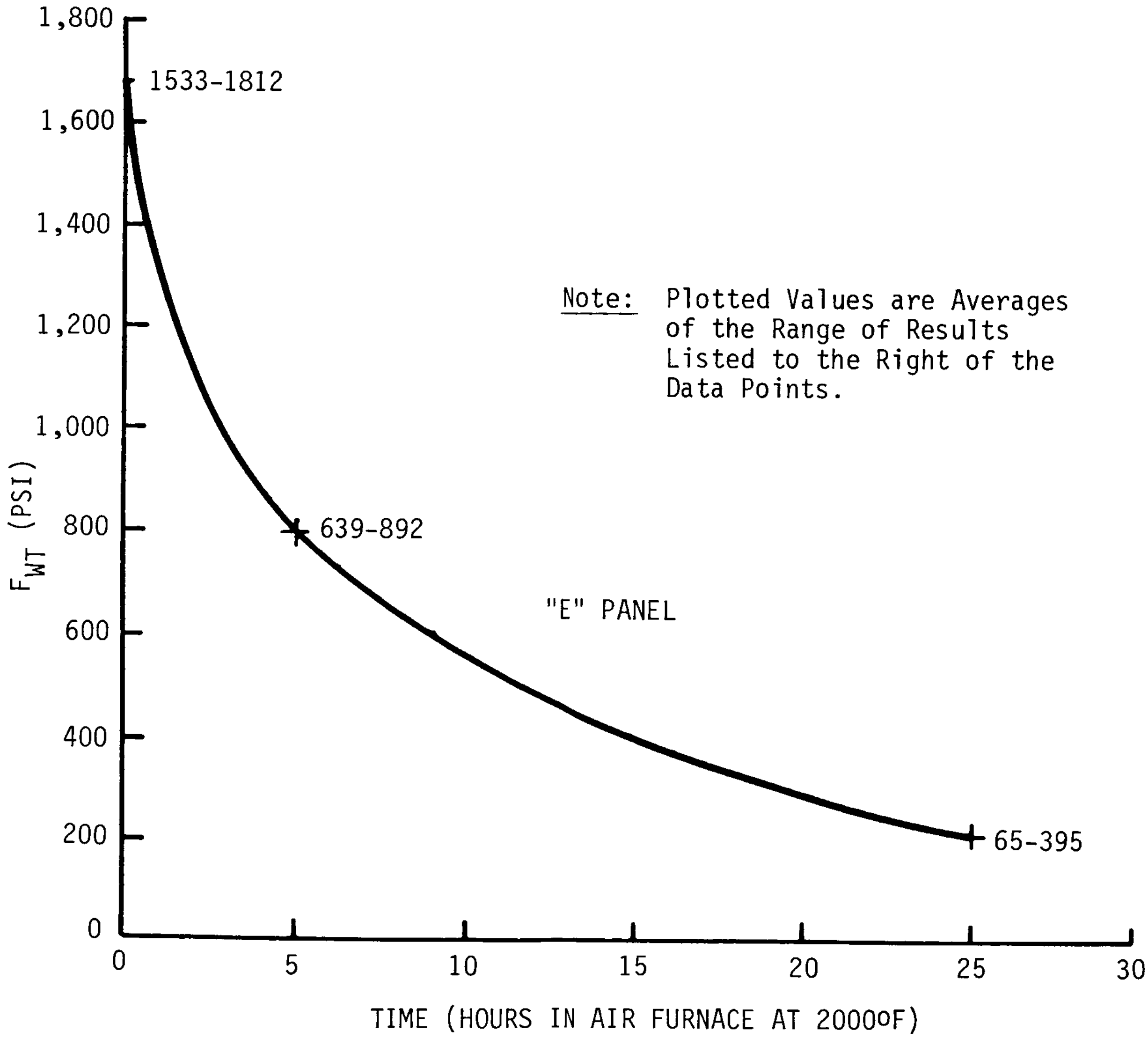
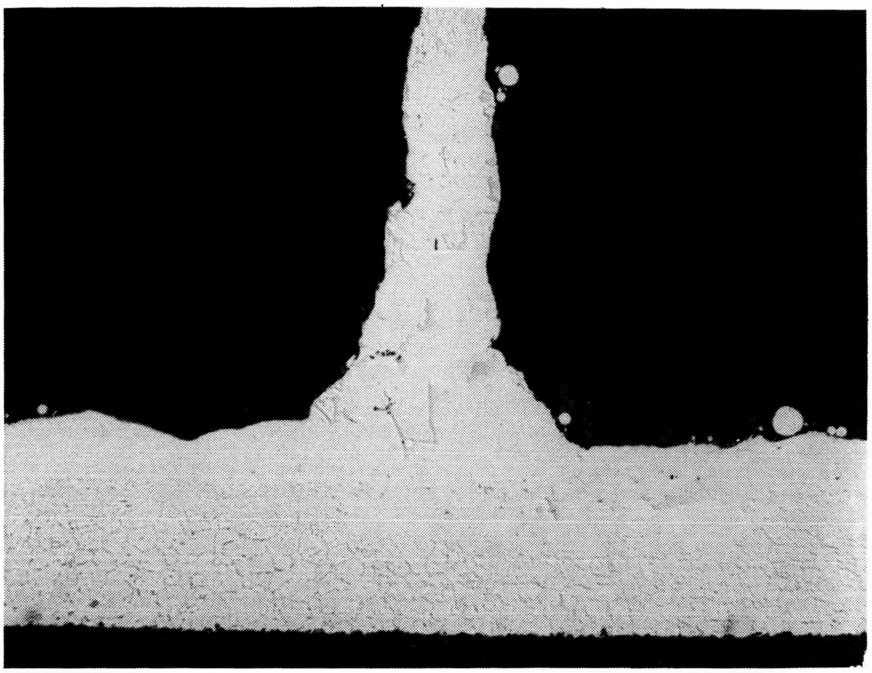
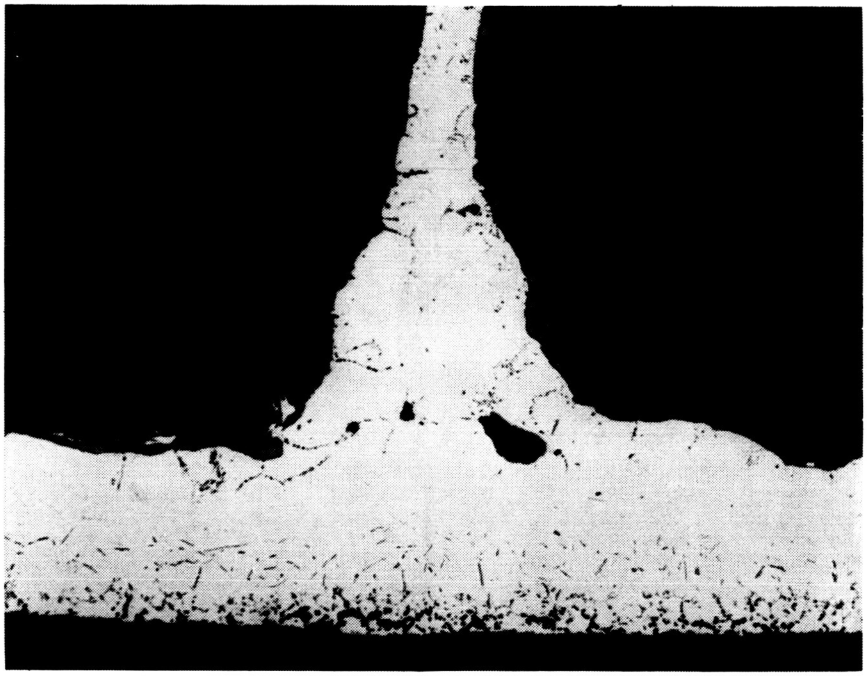


Figure 46. Flatwise Tension Strength Versus Exposure Time INCONEL 617 (Room Temperature Test)



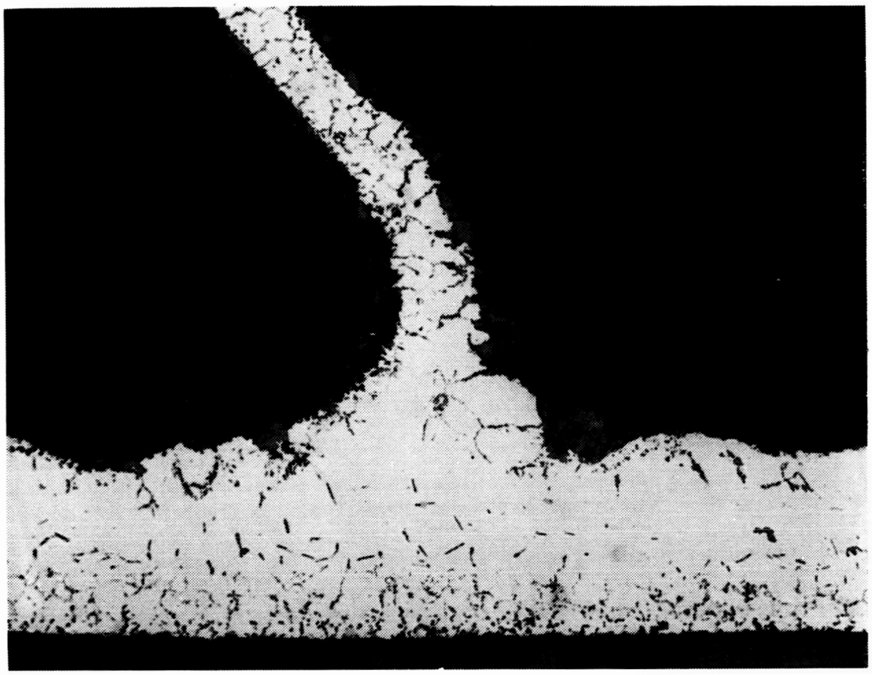
150X SCALE

Figure 47. Photomicrograph of Brazed Sandwich Joint--No Thermal Exposure



150X SCALE

Figure 48. Photomicrograph of Brazed Sandwich Joint--5 Hours of $2000^{\circ}F$ Exposure



150X SCALE

Figure 49. Photomicrograph of Brazed Sandwich Joint--25 Hours of $2000^{o}F$ Exposure

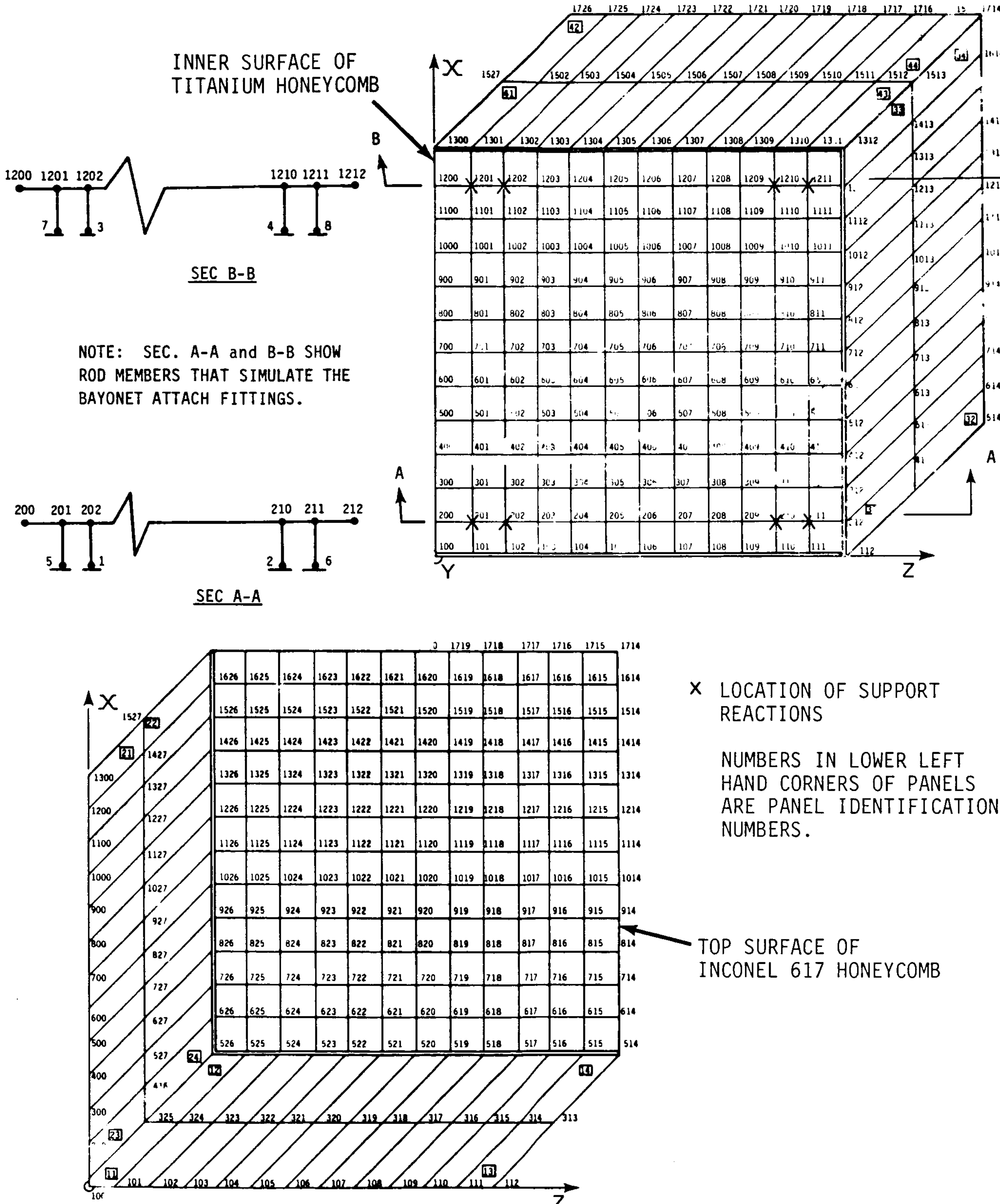
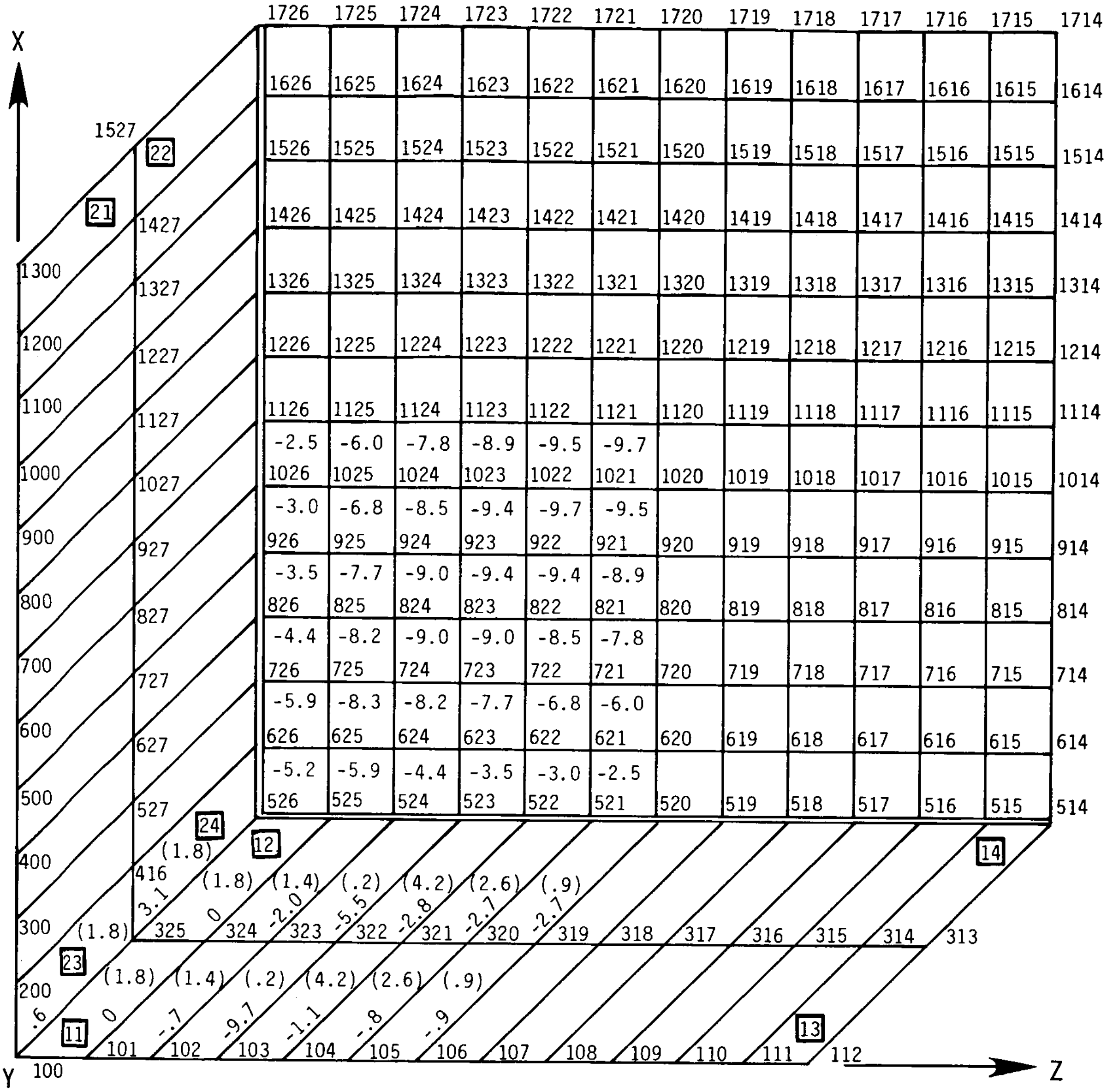


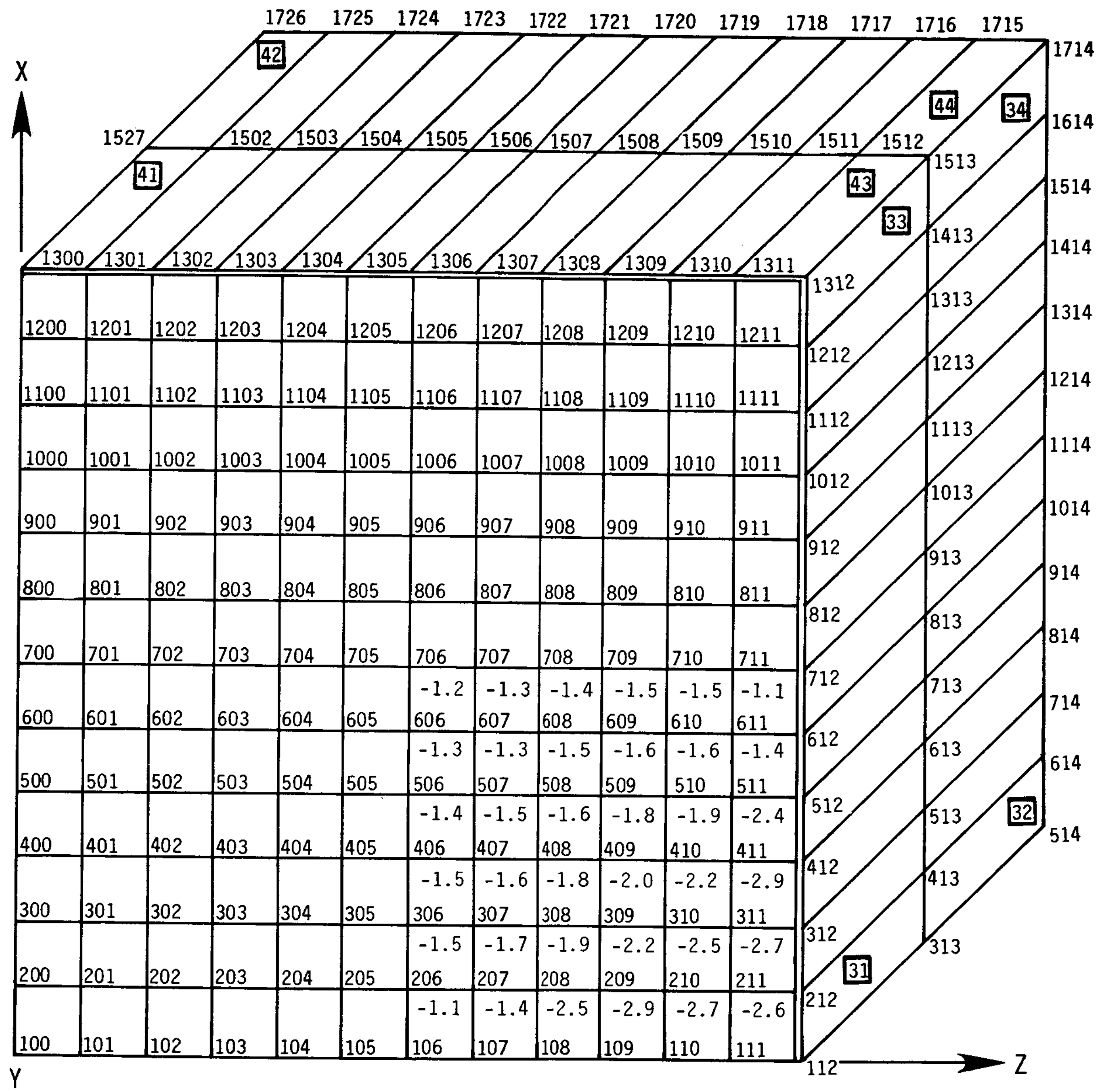
Figure 50. Finite Element Model



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

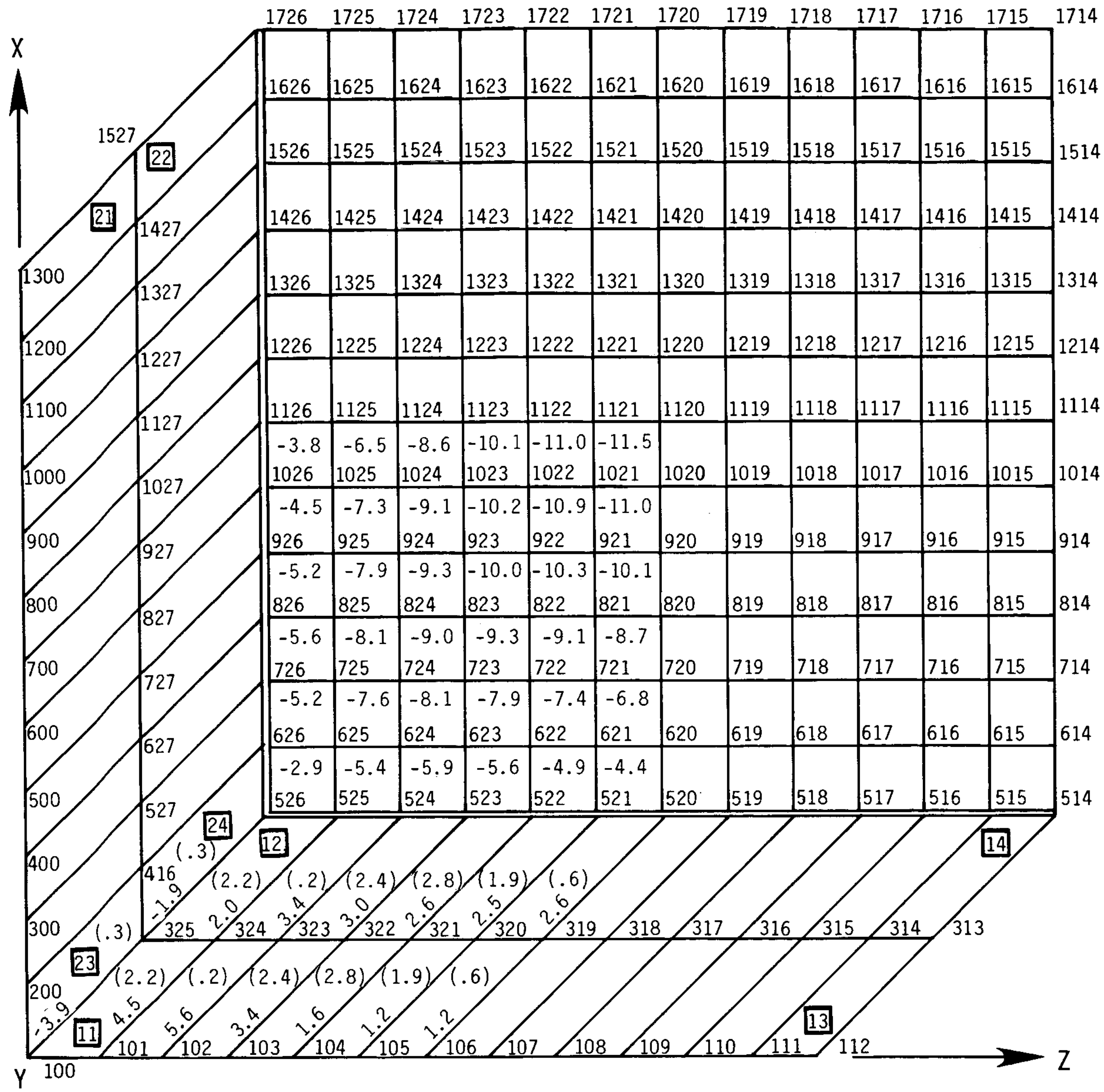
Figure 51-A. Ascent Crush Pressure Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

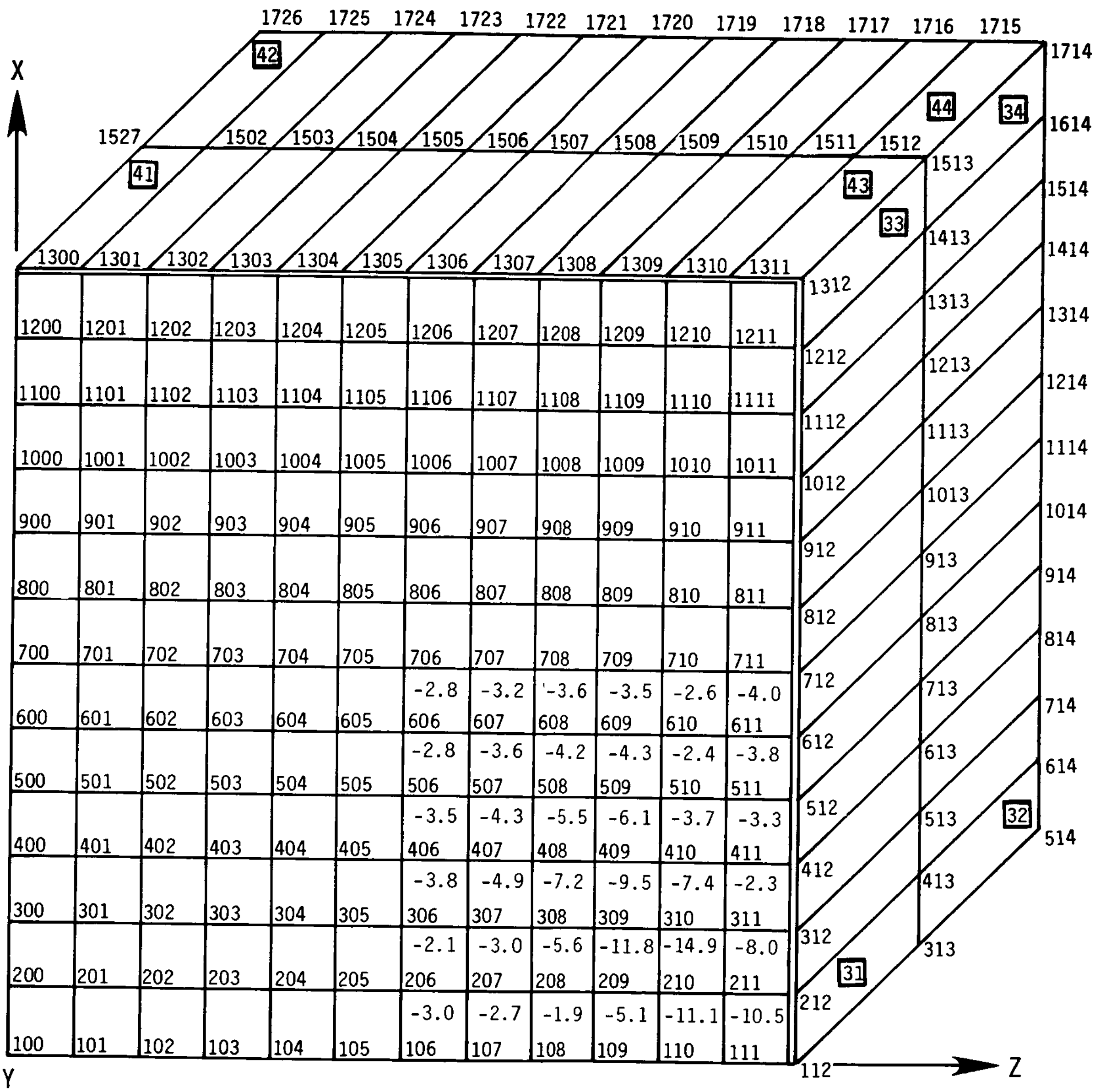
Figure 51-B. Ascent Crush Pressure Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

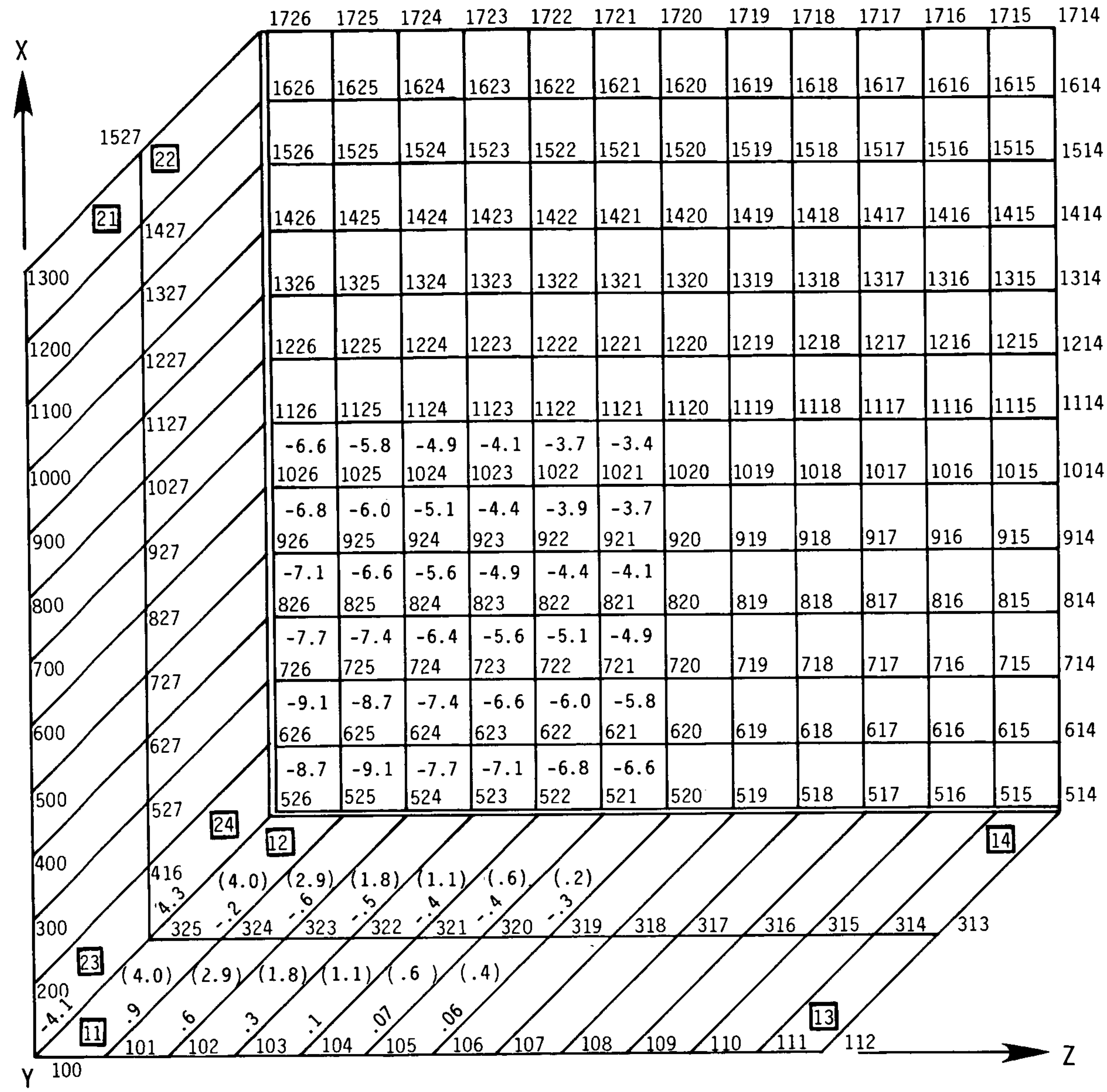
Figure 51-C. Ascent Blowoff Pressure Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

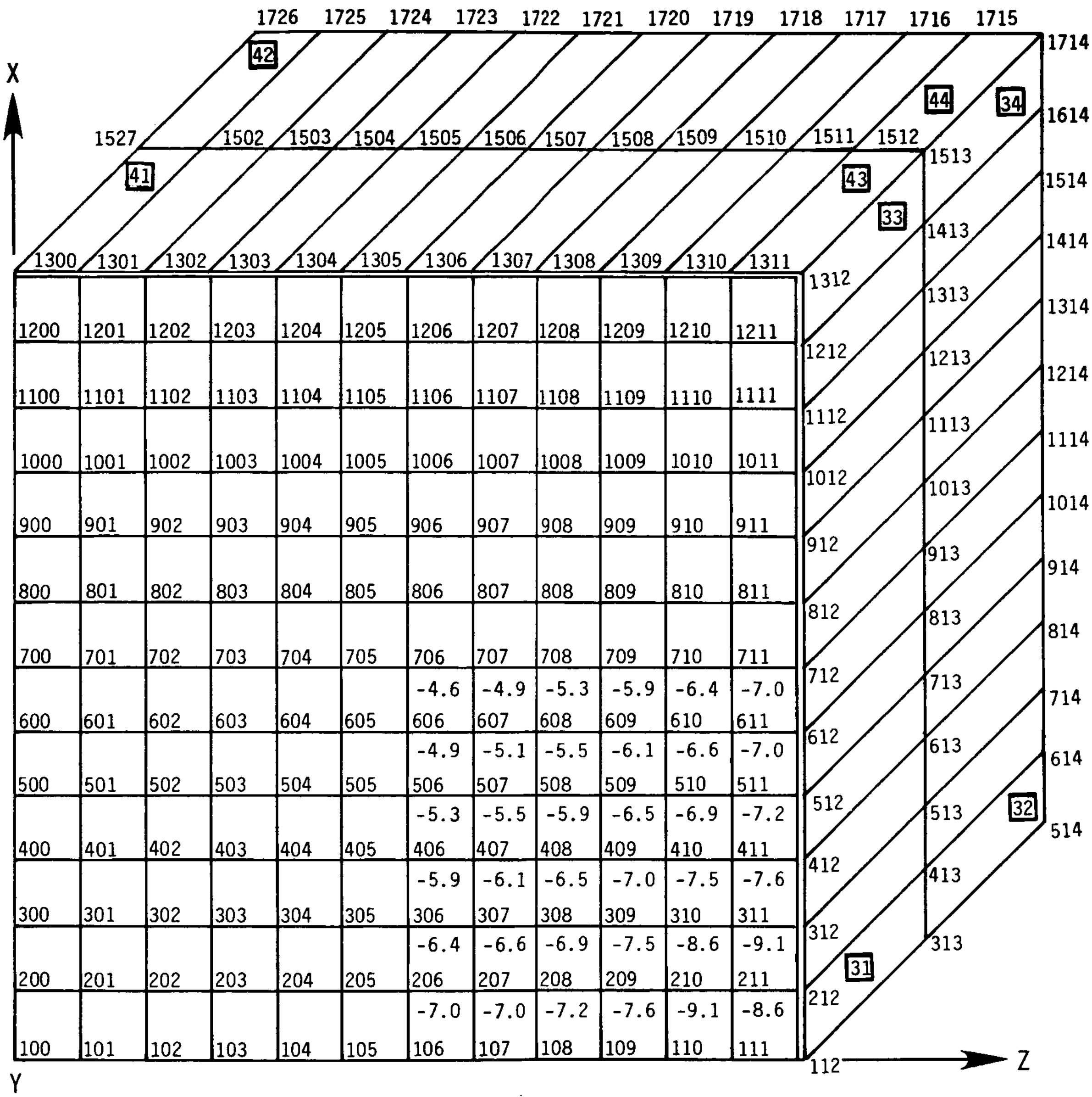
Figure 51-D. Ascent Blowoff Pressure Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

Figure 51-E. Descent Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

Figure 51-F. Descent Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output

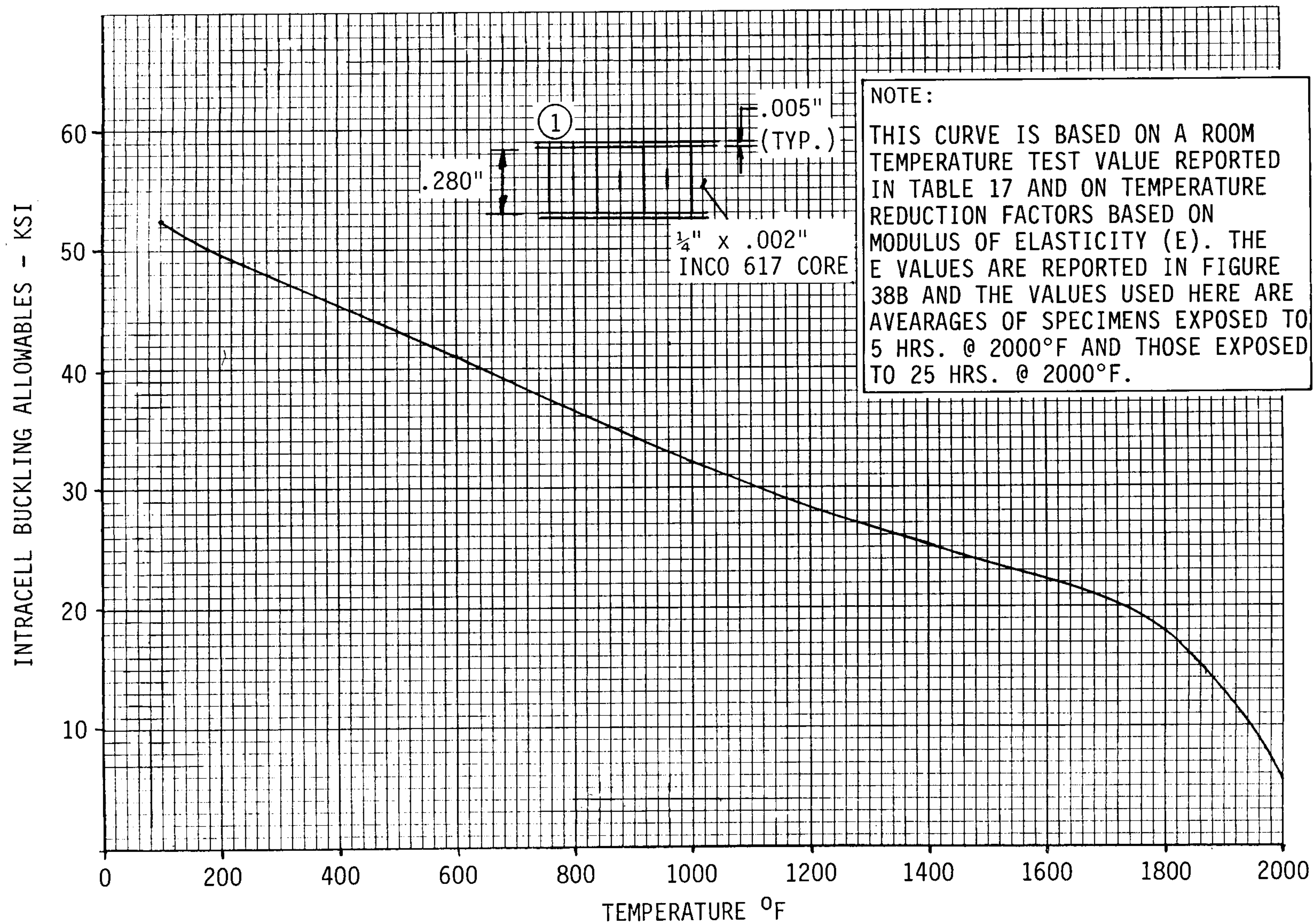


Figure 52. Inconel Honeycomb Compression Allowables

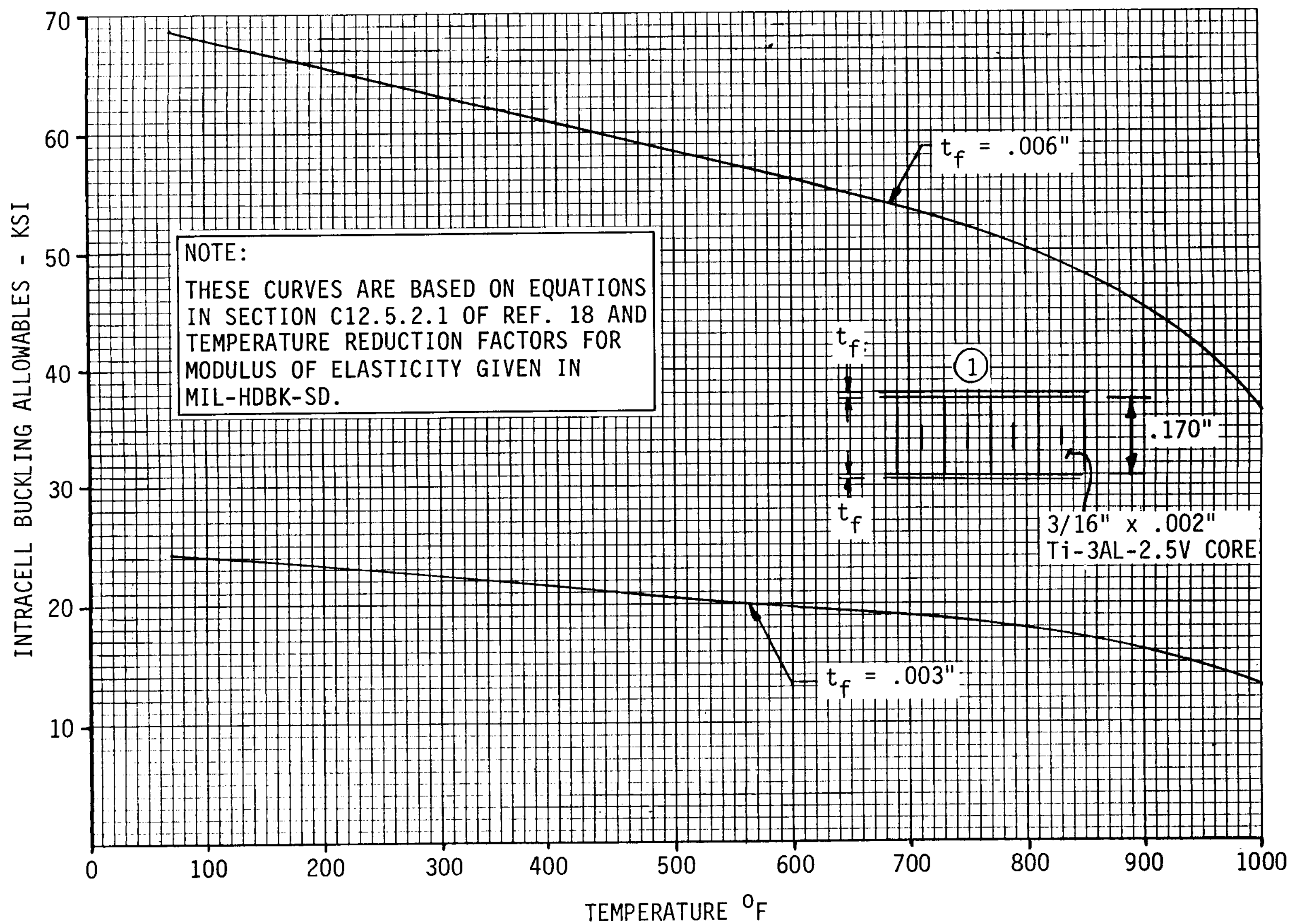


Figure 53. Titanium Honeycomb Compression Allowables

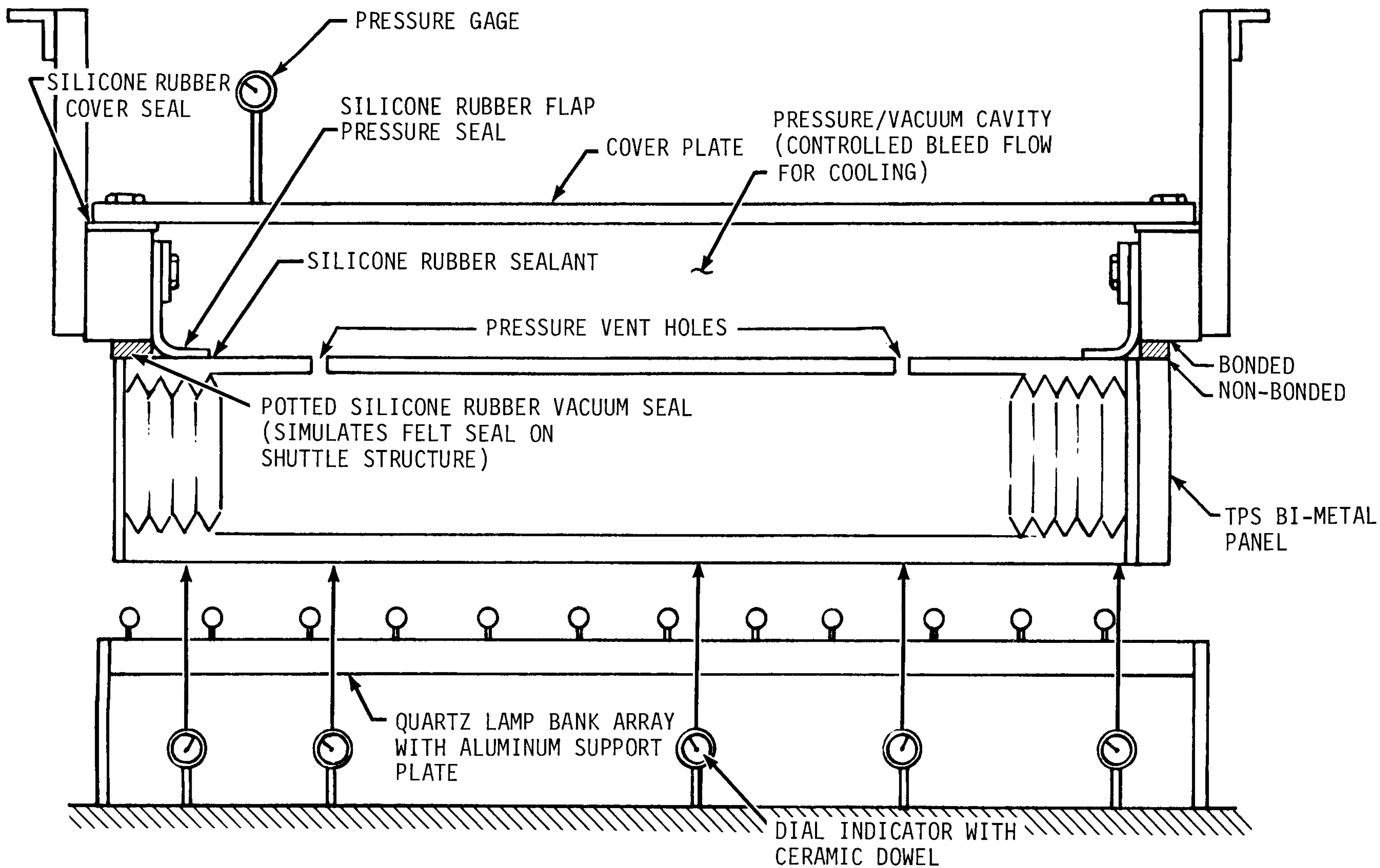


Figure 54. Schematic of Text Fixture for Thermal/Pressure Gradient Tests

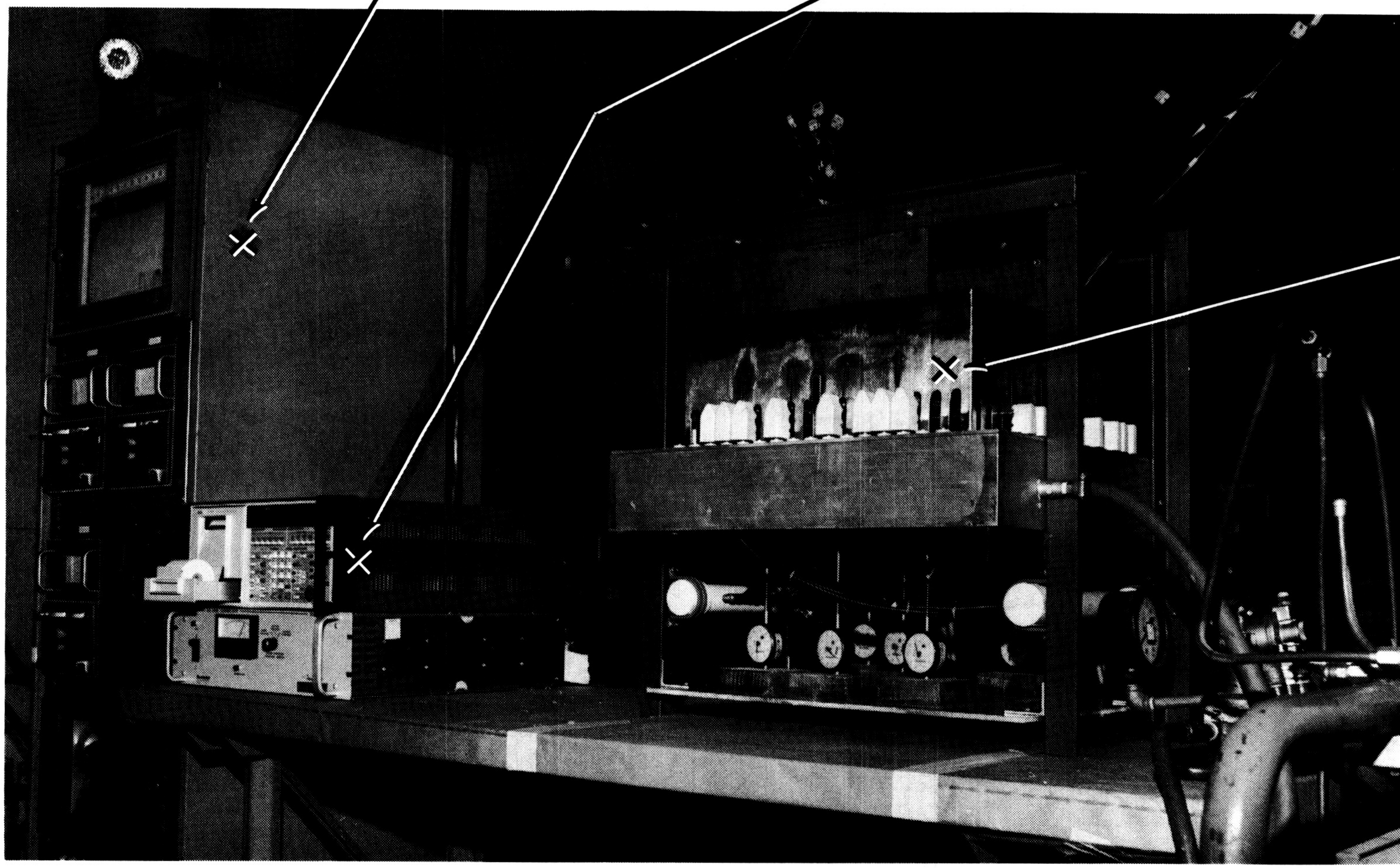


Figure 55. Test Apparatus for Pressure Testing with Thermal Gradient

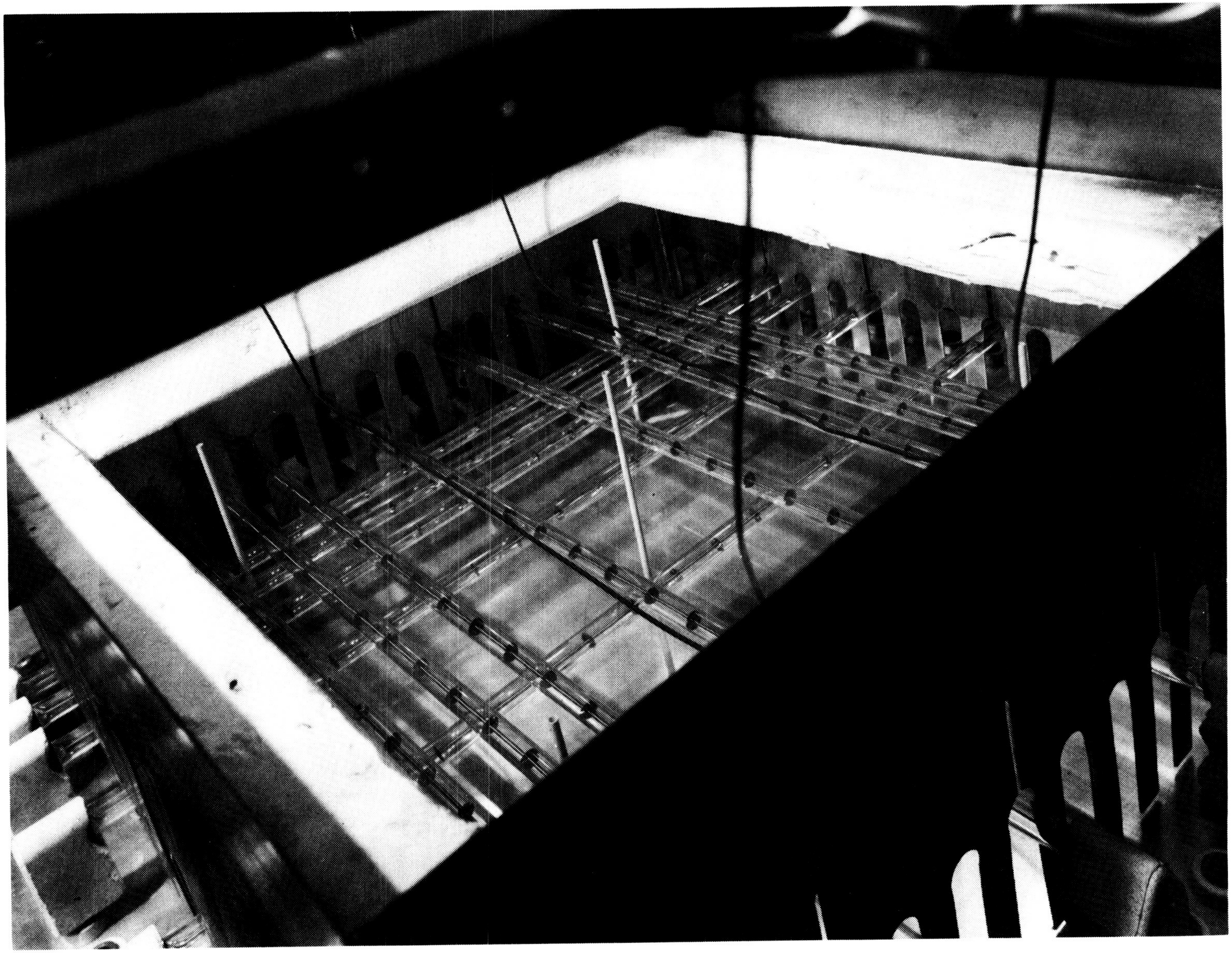


Figure 56. Quartz Lamp Bank Array

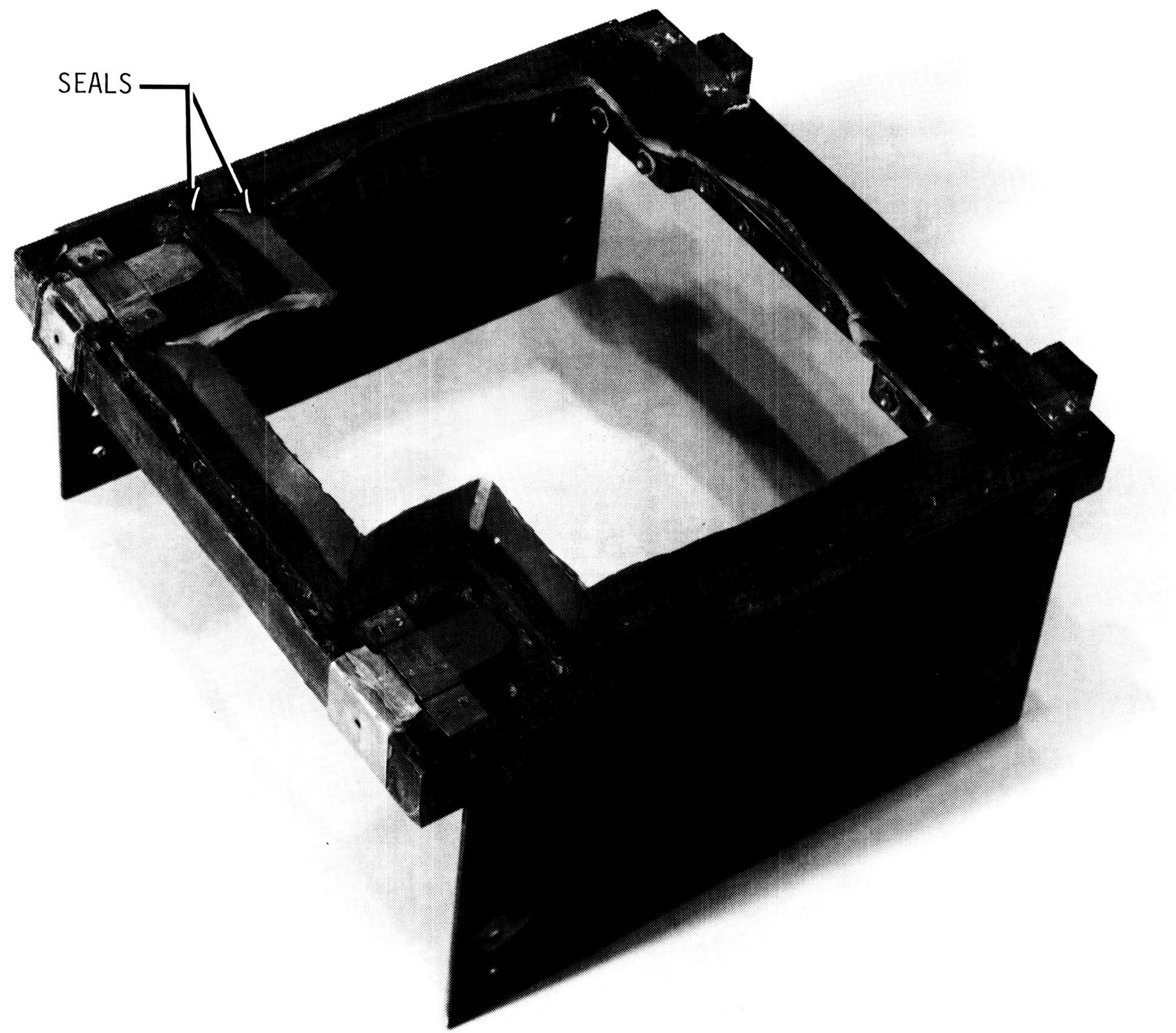


Figure 57. Test Chamber in Inverted Position

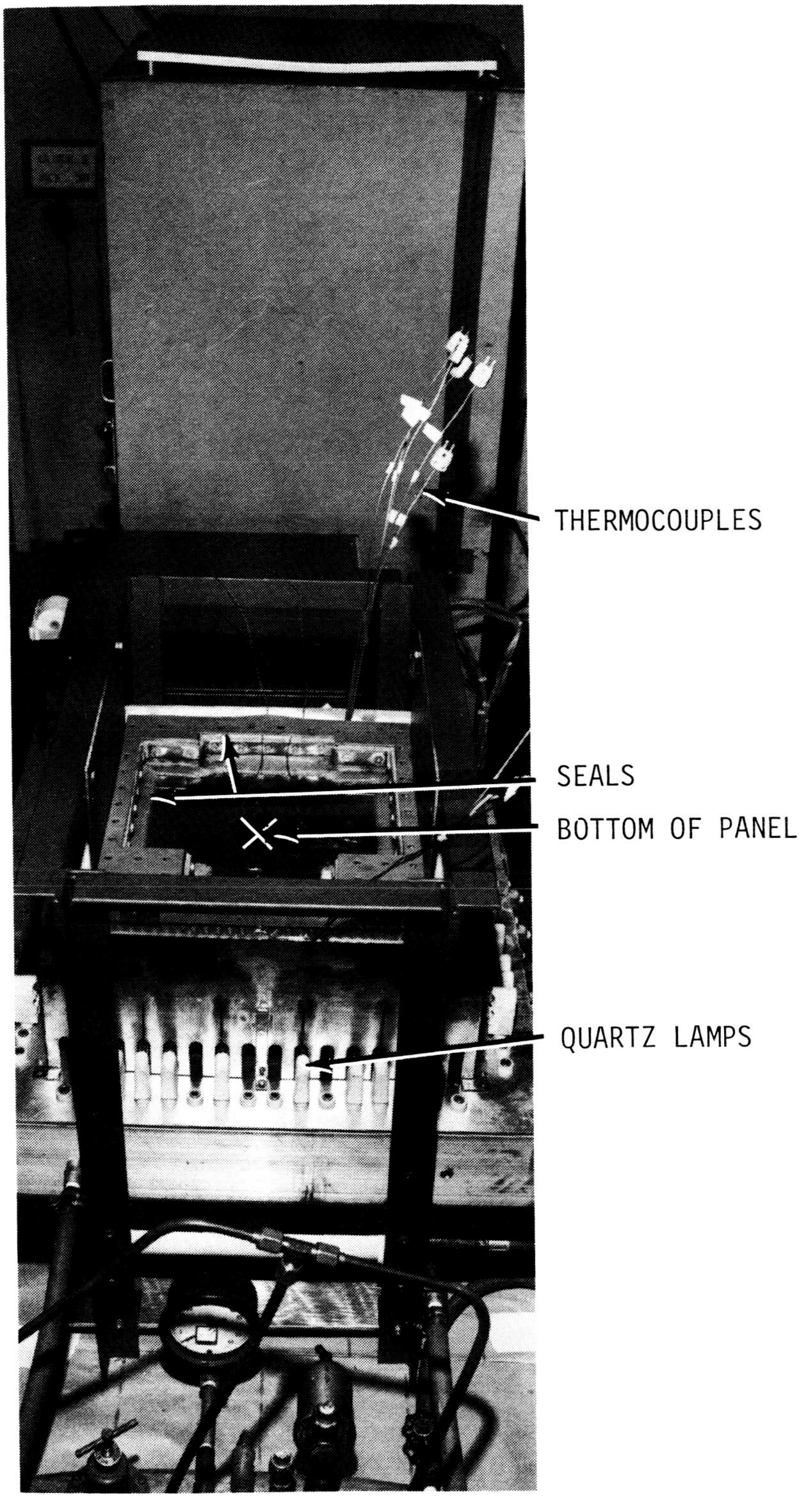


Figure 58. Pressure Test Apparatus

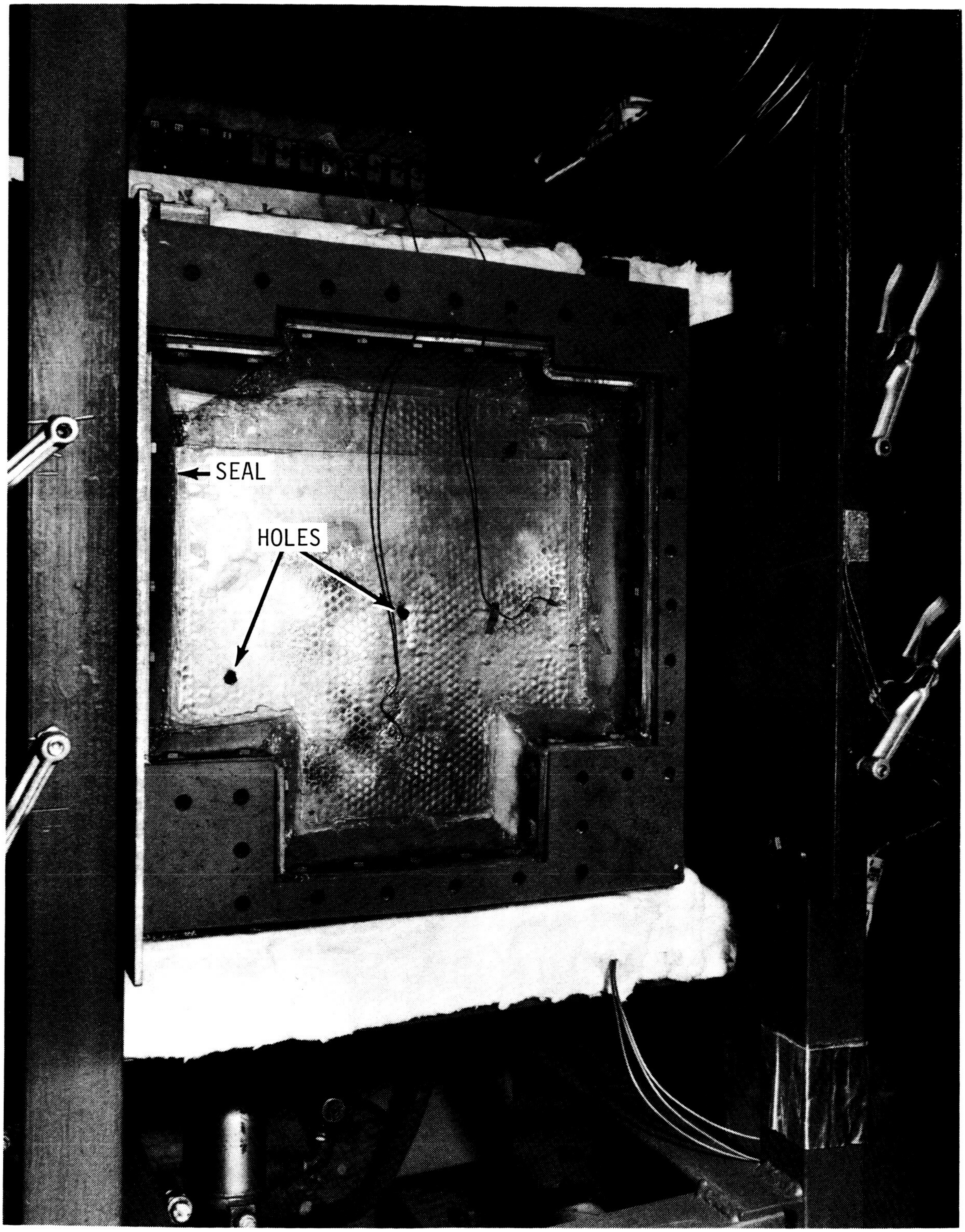


Figure 59. Bottom of Panel with Seals in Place for Testing

Figure 60. Panel Failed at 3.6 psi in the INCONEL 617 Material at the Bi-Metallic Joints During the Second Test, View 1

Figure 61. Panel Failed at 3.6 psi in the INCONEL 617 Material at the Bi-Metallic Joint During the Second Test, View 2

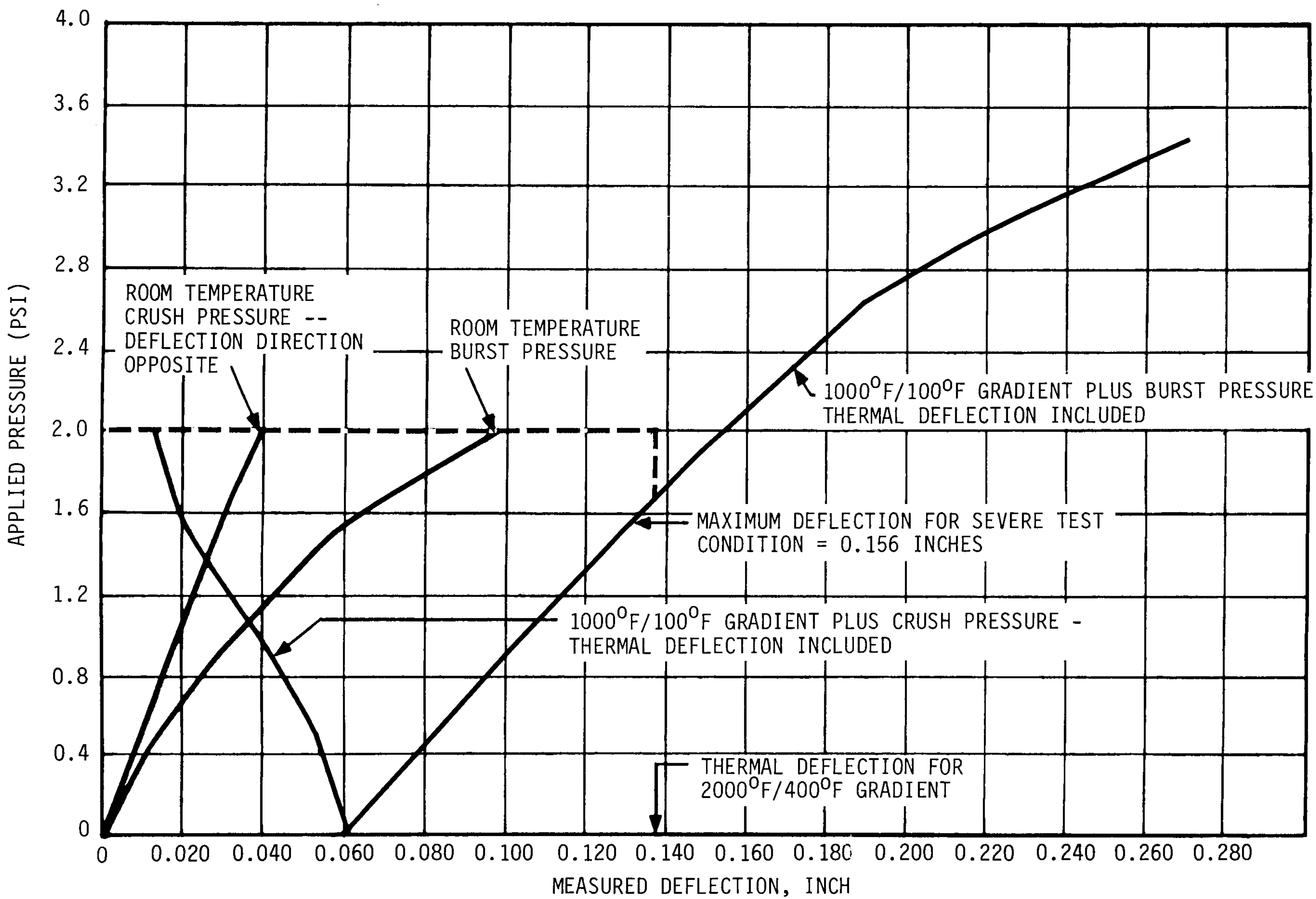
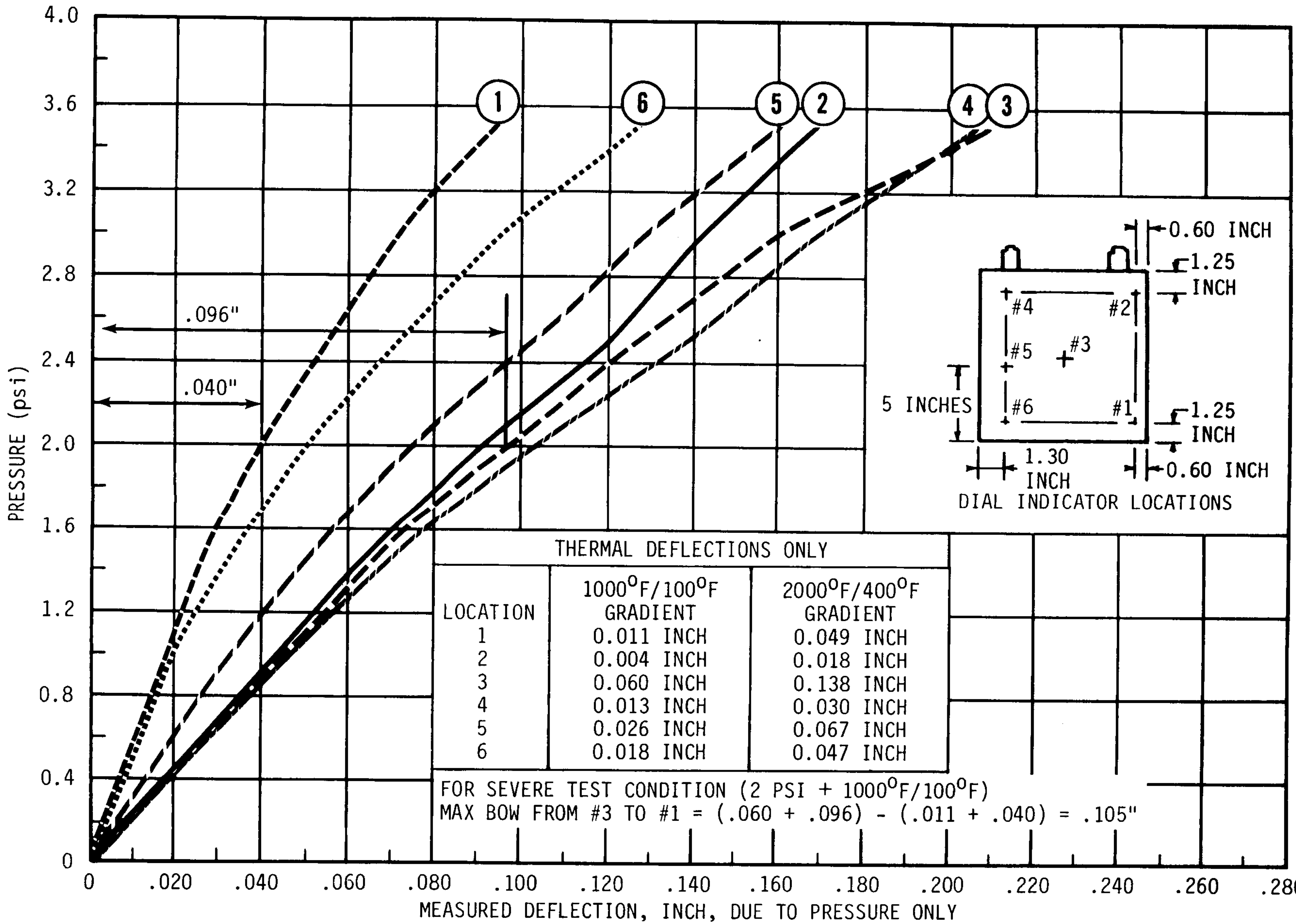


Figure 62. INCONEL 617, Ti-6-4, Silica Fiber Sandwich Panel Applied Pressure (psi) Versus Center Panel Deflections (inch) for Various Loading Conditions



THERMAL DEFLECTIONS ONLY

LOCATION	$1000^{0}F/100^{0}F$ GRADIENT	$2000^{0}F/400^{0}F$ GRADIENT
1	0.011 INCH	0.049 INCH
2	0.004 INCH	0.018 INCH
3	0.060 INCH	0.138 INCH
4	0.013 INCH	0.030 INCH
5	0.026 INCH	0.067 INCH
6	0.018 INCH	0.047 INCH

FOR SEVERE TEST CONDITION (2 PSI + $1000^{0}F/100^{0}F$)
MAX BOW FROM #3 TO #1 = (.060 + .096) - (.011 + .040) = .105"

Figure 63. INCONEL Bi-Metal Panel Deflections

APPENDIX

TPS THREE DIMENSIONAL "NASTRAN"
FINITE ELEMENT MODEL

THE FOLLOWING PAGES CONTAIN CODED SAMPLE

OF TPS PANEL FOR THREE DIMENSIONAL

"NASTRAN" FINITE ELEMENT ANALYSIS.

SAMPLE INPUT REPRESENTS BOTH PRESSURE

AND THERMAL STATIC ANALYSIS.

M S C / N A S T R A N

VERSION - 63

JUL 20, 1983

DIGITAL EQUIPMENT

MODEL VAX 11/750

ROHR

N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

```
ID A, PANEL
TIME 60
APP DISPLACEMENT
SOL 24
READ 9
$ BEGINNING OF RF ALTER 24$74
$ GENERATE SEQGP BULK DATA CARDS FOR EFFICIENCY IN SYMMETRIC DECOMP.
$ THE FOLLOWING ARE USER INPUT PARAMETERS
$ VALUE                      OPTION
$ SEQOUT--OUTPUT OPTIONS FOR SEQGP CARDS
$    0  DEFAULT-NO PRINTED OR PUNCH OUTPUT
$    1  PRINT TABLE OF INTERNAL/EXTERNAL SEQUENCE IN INTERNAL ORDER
$    2  TRANSMIT THE SEQGP CARDS TO THE SYSTEM PUNCH FILE
$    3  PRINT TABLE AND PUNCH SEQGP CARDS
$ NEWSEQ--OPTIONS FOR SEQUENCING LOGIC
$   -1  DO NOT RESEQUENCE
$    1  USE ACTIVE COLUMN SEQUENCING OPTION
$    2  USE BAND SEQUENCING OPTION
$    3  DEFAULT-RUN BOTH ACTIVE COLUMN AND BAND SEQUENCING--SAVE THE SEQU        ENCE
$          WITH THE LOWEST TIME ESTIMATE FOR DECOMPOSITION
$ SUPER--OPTIONS FOR TYPES OF SEQUENCING
$    0  DEFAULT-USE PASSIVE COLUMN SEQUENCING OPTION
$   -1  USE SUPERELEMENT SEQUENCING OPTION
$ FACTOR--USED FOR THE GENERATION OF THE INTERNAL SEQUENCE NUMBER
$    SEQID = FACTOR * SEID + SEQ NUMBER
$       DEFAULT = 10000
$ MPCX--OPTION FOR MPC PROCESSING
$   -1  DO NOT PROCESS MPC BULK DATA CARDS OR RIGID ELEMENTS
$    0  DEFAULT-PROCESS RIGID ELEMENTS ONLY
$    N  POSITIVE INTEGER IS THE NUMBER OF THE MPC SET TO PROCESS
$          ALONG WITH ANY RIGID ELEMENTS PRESENT
$ START--STARTING POINT OPTIONS
$    0  DEFAULT-PROGRAM SELECTS STARTING POINT
$    N  INTEGER IS NUMBER OF POINTS TO BE USED TO START SEQUENCING
ALTER 8
COND     NOSEQP,NEWSEQ $
SEQP   GEOM1,GEOM2,GEOM4,/GEOM1Q,MATPARM/C,Y,SEQOUT=0/V,Y,NEWSEQ=+3//
           C,Y,SUPER= 0/C,Y,FACTOR=10000/C,Y,MPCX=0/C,Y,START=0 $
EQUIV      GEOM1Q,GEOM1/ALWAYS $
LABEL    NOSEQP
$ END OF RF ALTER 24$74
CEND
```

```
                    C A S E    C O N T R O L   D E C K   E C H O
CARD
COUNT
 1      TITLE = TPS PANEL
 2      OUTPUT
 3      TEMP(MATERIAL)=2
 4      SPCFORCE=ALL
 5      $
 6      $
 7      $
 8      SUBCASE 1
 9      LABEL= TEMP. LOAD ONLY 1900 F/ 203 F
10      TEMP(LOAD)=2
11      $
12      DISPLACEMENT=ALL
13      ELSTRESS=ALL
14      ELFORCE=ALL
15      BEGIN BULK

          INPUT BULK DATA CARD COUNT =    1290
```

```
                                  S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
    1-        BAROR           2                       0.      0.      10.     1
    2-        CBAR    101     1       101     324                                     +B101
    3-        +B101   5
    4-        CBAR    102     1       102     323                                     +B102
    5-        +B102   5
    6-        CBAR    103     1       103     322                                     +B103
    7-        +B103   5
    8-        CBAR    104     1       104     321                                     +B104
    9-        +B104   5
   10-        CBAR    105     1       105     320                                     +B105
   11-        +B105   5
   12-        CBAR    106     1       106     319                                     +B106
   13-        +B106   5
   14-        CBAR    107     1       107     318                                     +B107
   15-        +B107   5
   16-        CBAR    108     1       108     317                                     +B108
   17-        +B108   5
   18-        CBAR    109     1       109     316                                     +B109
   19-        +B109   5
   20-        CBAR    110     1       110     315                                     +B110
   21-        +B110   5
   22-        CBAR    111     1       111     314                                     +B111
   23-        +B111   5
   24-        CBAR    200             200     416                                     +B200
   25-        +B200   6
   26-        CBAR    212             212     413                                     +B212
   27-        +B212   6
   28-        CBAR    300             300     527                                     +B300
   29-        +B300   6
   30-        CBAR    312             312     513                                     +B312
   31-        +B312   6
   32-        CBAR    314     1       314     515                                     +B314
   33-        +B314           5
   34-        CBAR    315     1       315     516                                     +B315
   35-        +B315           5
   36-        CBAR    316     1       316     517                                     +B316
   37-        +B316           5
   38-        CBAR    317     1       317     518                                     +B317
   39-        +B317           5
   40-        CBAR    318     1       318     519                                     +B318
   41-        +B318           5
   42-        CBAR    319     1       319     520                                     +B319
   43-        +B319           5
   44-        CBAR    320     1       320     521                                     +B320
   45-        +B320           5
   46-        CBAR    321     1       321     522                                     +B321
   47-        +B321           5
   48-        CBAR    322     1       322     523                                     +B322
   49-        +B322           5
   50-        CBAR    323     1       323     524                                     +B323
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                                    S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT   .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  51-   +B323           5
  52-   CBAR    324     1               324     525                                     +B324
  53-   +B324           5
  54-   CBAR    400                     400     627                                     +B400
  55-   +B400   6
  56-   CBAR    412                     412     613                                     +B412
  57-   +B412   6
  58-   CBAR    413                     413     614                                     +B413
  59-   +B413           6
  60-   CBAR    416                     416     626                                     +B416
  61-   +B416           6
  62-   CBAR    500                     500     727                                     +B500
  63-   +B500   6
  64-   CBAR    512                     512     713                                     +B512
  65-   +B512   6
  66-   CBAR    513                     513     714                                     +B513
  67-   +B513           6
  68-   CBAR    527                     527     726                                     +B527
  69-   +B527           6
  70-   CBAR    600                     600     827                                     +B600
  71-   +B600   6
  72-   CBAR    612                     612     813                                     +B612
  73-   +B612   6
  74-   CBAR    613                     613     814                                     +B613
  75-   +B613           6
  76-   CBAR    627                     627     826                                     +B627
  77-   +B627           6
  78-   CBAR    700                     700     927                                     +B700
  79-   +B700   6
  80-   CBAR    712                     712     913                                     +B712
  81-   +B712   6
  82-   CBAR    713                     713     914                                     +B713
  83-   +B713           6
  84-   CBAR    727                     727     926                                     +B727
  85-   +B727           6
  86-   CBAR    800                     800     1027                                    +B800
  87-   +B800   6
  88-   CBAR    812                     812     1013                                    +B812
  89-   +B812   6
  90-   CBAR    813                     813     1014                                    +B813
  91-   +B813           6
  92-   CBAR    827                     827     1026                                    +B827
  93-   +B827           6
  94-   CBAR    900                     900     1127                                    +B900
  95-   +B900   6
  96-   CBAR    912                     912     1113                                    +B912
  97-   +B912   6
  98-   CBAR    913                     913     1114                                    +B913
  99-   +B913           6
 100-   CBAR    927                     927     1126                                    +B927
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S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10
101-	+B927		6							
102-	CBAR	1000		1000	1227					+B1000
103-	+B1000	6								
104-	CBAR	1012		1012	1213					+B1012
105-	+B1012	6								
106-	CBAR	1013		1013	1214					+B1013
107-	+B1013		6							
108-	CBAR	1027		1027	1226					+B1027
109-	+B1027		6							
110-	CBAR	1100		1100	1327					+B1100
111-	+B1100	6								
112-	CBAR	1112		1112	1313					+B1112
113-	+B1112	6								
114-	CBAR	1113		1113	1314					+B1113
115-	+B1113		6							
116-	CBAR	1127		1127	1326					+B1127
117-	+B1127		6							
118-	CBAR	1200		1200	1427					+B1200
119-	+B1200	6								
120-	CBAR	1212		1212	1413					+B1212
121-	+B1212	6								
122-	CBAR	1213		1213	1414					+B1213
123-	+B1213		6							
124-	CBAR	1227		1227	1426					+B1227
125-	+B1227		6							
126-	CBAR	1301	1	1301	1502					+B1301
127-	+B1301	5								
128-	CBAR	1302	1	1302	1503					+B1302
129-	+B1302	5								
130-	CBAR	1303	1	1303	1504					+B1303
131-	+B1303	5								
132-	CBAR	1304	1	1304	1505					+B1304
133-	+B1304	5								
134-	CBAR	1305	1	1305	1506					+B1305
135-	+B1305	5								
136-	CBAR	1306	1	1306	1507					+B1306
137-	+B1306	5								
138-	CBAR	1307	1	1307	1508					+B1307
139-	+B1307	5								
140-	CBAR	1308	1	1308	1509					+B1308
141-	+B1308	5								
142-	CBAR	1309	1	1309	1510					+B1309
143-	+B1309	5								
144-	CBAR	1310	1	1310	1511					+B1310
145-	+B1310	5								
146-	CBAR	1311	1	1311	1512					+B1311
147-	+B1311	5								
148-	CBAR	1313		1313	1514					+B1313
149-	+B1313		6							
150-	CBAR	1327		1327	1526					+B1327

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
151-	+B1327		6							
152-	CBAR	1413		1413	1614					+B1413
153-	+B1413		6							
154-	CBAR	1427		1427	1626					+B1427
155-	+B1427		6							
156-	CBAR	1502	1	1502	1725					+B1502
157-	+B1502		5							
158-	CBAR	1503	1	1503	1724					+B1503
159-	+B1503		5							
160-	CBAR	1504	1	1504	1723					+B1504
161-	+B1504		5							
162-	CBAR	1505	1	1505	1722					+B1505
163-	+B1505		5							
164-	CBAR	1506	1	1506	1721					+B1506
165-	+B1506		5							
166-	CBAR	1507	1	1507	1720					+B1507
167-	+B1507		5							
168-	CBAR	1508	1	1508	1719					+B1508
169-	+B1508		5							
170-	CBAR	1509	1	1509	1718					+B1509
171-	+B1509		5							
172-	CBAR	1510	1	1510	1717					+B1510
173-	+B1510		5							
174-	CBAR	1511	1	1511	1716					+B1511
175-	+B1511		5							
176-	CBAR	1512	1	1512	1715					+B1512
177-	+B1512		5							
178-	CORD2R	2		-2.	1.057	-2.	-2.	1.057	12.	+C02
179-	+C02	12.	1.057	-2.0						
180-	CORD2R	4		-4.	2.114	-4.	-4.	2.114	12.	+C04
181-	+C04	12.	2.114	-4.0						
182-	CQUAD4	100	60	100	101	201	200			
183-	CQUAD4	101	60	101	102	202	201			
184-	CQUAD4	102	60	102	103	203	202			
185-	CQUAD4	103	60	103	104	204	203			
186-	CQUAD4	104	60	104	105	205	204			
187-	CQUAD4	105	60	105	106	206	205			
188-	CQUAD4	106	60	106	107	207	206			
189-	CQUAD4	107	60	107	108	208	207			
190-	CQUAD4	108	60	108	109	209	208			
191-	CQUAD4	109	60	109	110	210	209			
192-	CQUAD4	110	60	110	111	211	210			
193-	CQUAD4	111	60	111	112	212	211			
194-	CQUAD4	200	60	200	201	301	300			
195-	CQUAD4	201	600	201	202	302	301			
196-	CQUAD4	202	600	202	203	303	302			
197-	CQUAD4	203	600	203	204	304	303			
198-	CQUAD4	204	600	204	205	305	304			
199-	CQUAD4	205	600	205	206	306	305			
200-	CQUAD4	206	600	206	207	307	306			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
201-	CQUAD4	207	600	207	208	308	307			
202-	CQUAD4	208	600	208	209	309	308			
203-	CQUAD4	209	600	209	210	310	309			
204-	CQUAD4	210	600	210	211	311	310			
205-	CQUAD4	211	60	211	212	312	311			
206-	CQUAD4	300	60	300	301	401	400			
207-	CQUAD4	301	600	301	302	402	401			
208-	CQUAD4	302	6	302	303	403	402			
209-	CQUAD4	303	6	303	304	404	403			
210-	CQUAD4	304	6	304	305	405	404			
211-	CQUAD4	305	6	305	306	406	405			
212-	CQUAD4	306	6	306	307	407	406			
213-	CQUAD4	307	6	307	308	408	407			
214-	CQUAD4	308	6	308	309	409	408			
215-	CQUAD4	309	6	309	310	410	409			
216-	CQUAD4	310	600	310	311	411	410			
217-	CQUAD4	311	60	311	312	412	411			
218-	CQUAD4	400	60	400	401	501	500			
219-	CQUAD4	401	600	401	402	502	501			
220-	CQUAD4	402	6	402	403	503	502			
221-	CQUAD4	403	6	403	404	504	503			
222-	CQUAD4	404	6	404	405	505	504			
223-	CQUAD4	405	6	405	406	506	505			
224-	CQUAD4	406	6	406	407	507	506			
225-	CQUAD4	407	6	407	408	508	507			
226-	CQUAD4	408	6	408	409	509	508			
227-	CQUAD4	409	6	409	410	510	509			
228-	CQUAD4	410	600	410	411	511	510			
229-	CQUAD4	411	60	411	412	512	511			
230-	CQUAD4	500	60	500	501	601	600			
231-	CQUAD4	501	600	501	502	602	601			
232-	CQUAD4	502	6	502	503	603	602			
233-	CQUAD4	503	6	503	504	604	603			
234-	CQUAD4	504	6	504	505	605	604			
235-	CQUAD4	505	6	505	506	606	605			
236-	CQUAD4	506	6	506	507	607	606			
237-	CQUAD4	507	6	507	508	608	607			
238-	CQUAD4	508	6	508	509	609	608			
239-	CQUAD4	509	6	509	510	610	609			
240-	CQUAD4	510	600	510	511	611	610			
241-	CQUAD4	511	60	511	512	612	611			
242-	CQUAD4	515	5	515	514	614	615			
243-	CQUAD4	516	5	516	515	615	616			
244-	CQUAD4	517	5	517	516	616	617			
245-	CQUAD4	518	5	518	517	617	618			
246-	CQUAD4	519	5	519	518	618	619			
247-	CQUAD4	520	5	520	519	619	620			
248-	CQUAD4	521	5	521	520	620	621			
249-	CQUAD4	522	5	522	521	621	622			
250-	CQUAD4	523	5	523	522	622	623			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
251-	CQUAD4	524	5	524	523	623	624			
252-	CQUAD4	525	5	525	524	624	625			
253-	CQUAD4	526	5	526	525	625	626			
254-	CQUAD4	600	60	600	601	701	700			
255-	CQUAD4	601	600	601	602	702	701			
256-	CQUAD4	602	6	602	603	703	702			
257-	CQUAD4	603	6	603	604	704	703			
258-	CQUAD4	604	6	604	605	705	704			
259-	CQUAD4	605	6	605	606	706	705			
260-	CQUAD4	606	6	606	607	707	706			
261-	CQUAD4	607	6	607	608	708	707			
262-	CQUAD4	608	6	608	609	709	708			
263-	CQUAD4	609	6	609	610	710	709			
264-	CQUAD4	610	600	610	611	711	710			
265-	CQUAD4	611	60	611	612	712	711			
266-	CQUAD4	615	5	615	614	714	715			
267-	CQUAD4	616	5	616	615	715	716			
268-	CQUAD4	617	5	617	616	716	717			
269-	CQUAD4	618	5	618	617	717	718			
270-	CQUAD4	619	5	619	618	718	719			
271-	CQUAD4	620	5	620	619	719	720			
272-	CQUAD4	621	5	621	620	720	721			
273-	CQUAD4	622	5	622	621	721	722			
274-	CQUAD4	623	5	623	622	722	723			
275-	CQUAD4	624	5	624	623	723	724			
276-	CQUAD4	625	5	625	624	724	725			
277-	CQUAD4	626	5	626	625	725	726			
278-	CQUAD4	700	60	700	701	801	800			
279-	CQUAD4	701	600	701	702	802	801			
280-	CQUAD4	702	6	702	703	803	802			
281-	CQUAD4	703	6	703	704	804	803			
282-	CQUAD4	704	6	704	705	805	804			
283-	CQUAD4	705	6	705	706	806	805			
284-	CQUAD4	706	6	706	707	807	806			
285-	CQUAD4	707	6	707	708	808	807			
286-	CQUAD4	708	6	708	709	809	808			
287-	CQUAD4	709	6	709	710	810	809			
288-	CQUAD4	710	600	710	711	811	810			
289-	CQUAD4	711	60	711	712	812	811			
290-	CQUAD4	715	5	715	714	814	815			
291-	CQUAD4	716	5	716	715	815	816			
292-	CQUAD4	717	5	717	716	816	817			
293-	CQUAD4	718	5	718	717	817	818			
294-	CQUAD4	719	5	719	718	818	819			
295-	CQUAD4	720	5	720	719	819	820			
296-	CQUAD4	721	5	721	720	820	821			
297-	CQUAD4	722	5	722	721	821	822			
298-	CQUAD4	723	5	723	722	822	823			
299-	CQUAD4	724	5	724	723	823	824			
300-	CQUAD4	725	5	725	724	824	825			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
301-	CQUAD4	726	5	726	725	825	826			
302-	CQUAD4	800	60	800	801	901	900			
303-	CQUAD4	801	600	801	802	902	901			
304-	CQUAD4	802	6	802	803	903	902			
305-	CQUAD4	803	6	803	804	904	903			
306-	CQUAD4	804	6	804	805	905	904			
307-	CQUAD4	805	6	805	806	906	905			
308-	CQUAD4	806	6	806	807	907	906			
309-	CQUAD4	807	6	807	808	908	907			
310-	CQUAD4	808	6	808	809	909	908			
311-	CQUAD4	809	6	809	810	910	909			
312-	CQUAD4	810	600	810	811	911	910			
313-	CQUAD4	811	60	811	812	912	911			
314-	CQUAD4	815	5	815	814	914	915			
315-	CQUAD4	816	5	816	815	915	916			
316-	CQUAD4	817	5	817	816	916	917			
317-	CQUAD4	818	5	818	817	917	918			
318-	CQUAD4	819	5	819	818	918	919			
319-	CQUAD4	820	5	820	819	919	920			
320-	CQUAD4	821	5	821	820	920	921			
321-	CQUAD4	822	5	822	821	921	922			
322-	CQUAD4	823	5	823	822	922	923			
323-	CQUAD4	824	5	824	823	923	924			
324-	CQUAD4	825	5	825	824	924	925			
325-	CQUAD4	826	5	826	825	925	926			
326-	CQUAD4	900	60	900	901	1001	1000			
327-	CQUAD4	901	600	901	902	1002	1001			
328-	CQUAD4	902	6	902	903	1003	1002			
329-	CQUAD4	903	6	903	904	1004	1003			
330-	CQUAD4	904	6	904	905	1005	1004			
331-	CQUAD4	905	6	905	906	1006	1005			
332-	CQUAD4	906	6	906	907	1007	1006			
333-	CQUAD4	907	6	907	908	1008	1007			
334-	CQUAD4	908	6	908	909	1009	1008			
335-	CQUAD4	909	6	909	910	1010	1009			
336-	CQUAD4	910	600	910	911	1011	1010			
337-	CQUAD4	911	60	911	912	1012	1011			
338-	CQUAD4	915	5	915	914	1014	1015			
339-	CQUAD4	916	5	916	915	1015	1016			
340-	CQUAD4	917	5	917	916	1016	1017			
341-	CQUAD4	918	5	918	917	1017	1018			
342-	CQUAD4	919	5	919	918	1018	1019			
343-	CQUAD4	920	5	920	919	1019	1020			
344-	CQUAD4	921	5	921	920	1020	1021			
345-	CQUAD4	922	5	922	921	1021	1022			
346-	CQUAD4	923	5	923	922	1022	1023			
347-	CQUAD4	924	5	924	923	1023	1024			
348-	CQUAD4	925	5	925	924	1024	1025			
349-	CQUAD4	926	5	926	925	1025	1026			
350-	CQUAD4	1000	60	1000	1001	1101	1100			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
351-	CQUAD4	1001	600	1001	1002	1102	1101			
352-	CQUAD4	1002	6	1002	1003	1103	1102			
353-	CQUAD4	1003	6	1003	1004	1104	1103			
354-	CQUAD4	1004	6	1004	1005	1105	1104			
355-	CQUAD4	1005	6	1005	1006	1106	1105			
356-	CQUAD4	1006	6	1006	1007	1107	1106			
357-	CQUAD4	1007	6	1007	1008	1108	1107			
358-	CQUAD4	1008	6	1008	1009	1109	1108			
359-	CQUAD4	1009	6	1009	1010	1110	1109			
360-	CQUAD4	1010	600	1010	1011	1111	1110			
361-	CQUAD4	1011	60	1011	1012	1112	1111			
362-	CQUAD4	1015	5	1015	1014	1114	1115			
363-	CQUAD4	1016	5	1016	1015	1115	1116			
364-	CQUAD4	1017	5	1017	1016	1116	1117			
365-	CQUAD4	1018	5	1018	1017	1117	1118			
366-	CQUAD4	1019	5	1019	1018	1118	1119			
367-	CQUAD4	1020	5	1020	1019	1119	1120			
368-	CQUAD4	1021	5	1021	1020	1120	1121			
369-	CQUAD4	1022	5	1022	1021	1121	1122			
370-	CQUAD4	1023	5	1023	1022	1122	1123			
371-	CQUAD4	1024	5	1024	1023	1123	1124			
372-	CQUAD4	1025	5	1025	1024	1124	1125			
373-	CQUAD4	1026	5	1026	1025	1125	1126			
374-	CQUAD4	1100	60	1100	1101	1201	1200			
375-	CQUAD4	1101	600	1101	1102	1202	1201			
376-	CQUAD4	1102	600	1102	1103	1203	1202			
377-	CQUAD4	1103	600	1103	1104	1204	1203			
378-	CQUAD4	1104	600	1104	1105	1205	1204			
379-	CQUAD4	1105	600	1105	1106	1206	1205			
380-	CQUAD4	1106	600	1106	1107	1207	1206			
381-	CQUAD4	1107	600	1107	1108	1208	1207			
382-	CQUAD4	1108	600	1108	1109	1209	1208			
383-	CQUAD4	1109	600	1109	1110	1210	1209			
384-	CQUAD4	1110	600	1110	1111	1211	1210			
385-	CQUAD4	1111	60	1111	1112	1212	1211			
386-	CQUAD4	1115	5	1115	1114	1214	1215			
387-	CQUAD4	1116	5	1116	1115	1215	1216			
388-	CQUAD4	1117	5	1117	1116	1216	1217			
389-	CQUAD4	1118	5	1118	1117	1217	1218			
390-	CQUAD4	1119	5	1119	1118	1218	1219			
391-	CQUAD4	1120	5	1120	1119	1219	1220			
392-	CQUAD4	1121	5	1121	1120	1220	1221			
393-	CQUAD4	1122	5	1122	1121	1221	1222			
394-	CQUAD4	1123	5	1123	1122	1222	1223			
395-	CQUAD4	1124	5	1124	1123	1223	1224			
396-	CQUAD4	1125	5	1125	1124	1224	1225			
397-	CQUAD4	1126	5	1126	1125	1225	1226			
398-	CQUAD4	1200	60	1200	1201	1301	1300			
399-	CQUAD4	1201	60	1201	1202	1302	1301			
400-	CQUAD4	1202	60	1202	1203	1303	1302			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10
401-	CQUAD4	1203	60	1203	1204	1304	1303			
402-	CQUAD4	1204	60	1204	1205	1305	1304			
403-	CQUAD4	1205	60	1205	1206	1306	1305			
404-	CQUAD4	1206	60	1206	1207	1307	1306			
405-	CQUAD4	1207	60	1207	1208	1308	1307			
406-	CQUAD4	1208	60	1208	1209	1309	1308			
407-	CQUAD4	1209	60	1209	1210	1310	1309			
408-	CQUAD4	1210	60	1210	1211	1311	1310			
409-	CQUAD4	1211	60	1211	1212	1312	1311			
410-	CQUAD4	1215	5	1215	1214	1314	1315			
411-	CQUAD4	1216	5	1216	1215	1315	1316			
412-	CQUAD4	1217	5	1217	1216	1316	1317			
413-	CQUAD4	1218	5	1218	1217	1317	1318			
414-	CQUAD4	1219	5	1219	1218	1318	1319			
415-	CQUAD4	1220	5	1220	1219	1319	1320			
416-	CQUAD4	1221	5	1221	1220	1320	1321			
417-	CQUAD4	1222	5	1222	1221	1321	1322			
418-	CQUAD4	1223	5	1223	1222	1322	1323			
419-	CQUAD4	1224	5	1224	1223	1323	1324			
420-	CQUAD4	1225	5	1225	1224	1324	1325			
421-	CQUAD4	1226	5	1226	1225	1325	1326			
422-	CQUAD4	1315	5	1315	1314	1414	1415			
423-	CQUAD4	1316	5	1316	1315	1415	1416			
424-	CQUAD4	1317	5	1317	1316	1416	1417			
425-	CQUAD4	1318	5	1318	1317	1417	1418			
426-	CQUAD4	1319	5	1319	1318	1418	1419			
427-	CQUAD4	1320	5	1320	1319	1419	1420			
428-	CQUAD4	1321	5	1321	1320	1420	1421			
429-	CQUAD4	1322	5	1322	1321	1421	1422			
430-	CQUAD4	1323	5	1323	1322	1422	1423			
431-	CQUAD4	1324	5	1324	1323	1423	1424			
432-	CQUAD4	1325	5	1325	1324	1424	1425			
433-	CQUAD4	1326	5	1326	1325	1425	1426			
434-	CQUAD4	1415	5	1415	1414	1514	1515			
435-	CQUAD4	1416	5	1416	1415	1515	1516			
436-	CQUAD4	1417	5	1417	1416	1516	1517			
437-	CQUAD4	1418	5	1418	1417	1517	1518			
438-	CQUAD4	1419	5	1419	1418	1518	1519			
439-	CQUAD4	1420	5	1420	1419	1519	1520			
440-	CQUAD4	1421	5	1421	1420	1520	1521			
441-	CQUAD4	1422	5	1422	1421	1521	1522			
442-	CQUAD4	1423	5	1423	1422	1522	1523			
443-	CQUAD4	1424	5	1424	1423	1523	1524			
444-	CQUAD4	1425	5	1425	1424	1524	1525			
445-	CQUAD4	1426	5	1426	1425	1525	1526			
446-	CQUAD4	1515	5	1515	1514	1614	1615			
447-	CQUAD4	1516	5	1516	1515	1615	1616			
448-	CQUAD4	1517	5	1517	1516	1616	1617			
449-	CQUAD4	1518	5	1518	1517	1617	1618			
450-	CQUAD4	1519	5	1519	1518	1618	1619			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
451-	CQUAD4	1520	5	1520	1519	1619	1620			
452-	CQUAD4	1521	5	1521	1520	1620	1621			
453-	CQUAD4	1522	5	1522	1521	1621	1622			
454-	CQUAD4	1523	5	1523	1522	1622	1623			
455-	CQUAD4	1524	5	1524	1523	1623	1624			
456-	CQUAD4	1525	5	1525	1524	1624	1625			
457-	CQUAD4	1526	5	1526	1525	1625	1626			
458-	CQUAD4	1615	5	1615	1614	1714	1715			
459-	CQUAD4	1616	5	1616	1615	1715	1716			
460-	CQUAD4	1617	5	1617	1616	1716	1717			
461-	CQUAD4	1618	5	1618	1617	1717	1718			
462-	CQUAD4	1619	5	1619	1618	1718	1719			
463-	CQUAD4	1620	5	1620	1619	1719	1720			
464-	CQUAD4	1621	5	1621	1620	1720	1721			
465-	CQUAD4	1622	5	1622	1621	1721	1722			
466-	CQUAD4	1623	5	1623	1622	1722	1723			
467-	CQUAD4	1624	5	1624	1623	1723	1724			
468-	CQUAD4	1625	5	1625	1624	1724	1725			
469-	CQUAD4	1626	5	1626	1625	1725	1726			
470-	CROD	1	1	1	202	2	1	2	210	
471-	CROD	3	1	3	1202	4	1	4	1210	
472-	CROD	100	3	100	325					
473-	CROD	112	3	112	313					
474-	CROD	313	3	313	514					
475-	CROD	325	3	325	526					
476-	CROD	1300	3	1300	1527					
477-	CROD	1312	3	1312	1513					
478-	CROD	1513	3	1513	1714					
479-	CROD	1527	3	1527	1726					
480-	CSHEAR	11	1	100	101	324	325			
481-	CSHEAR	12	1	325	324	525	526			
482-	CSHEAR	13	1	111	112	313	314			
483-	CSHEAR	14	1	314	313	514	515			
484-	CSHEAR	21	2	1300	1200	1427	1527			
485-	CSHEAR	22	2	1527	1427	1626	1726			
486-	CSHEAR	23	2	200	100	325	416			
487-	CSHEAR	24	2	416	325	526	626			
488-	CSHEAR	31	3	212	112	313	413			
489-	CSHEAR	32	3	413	313	514	614			
490-	CSHEAR	34	3	1312	1212	1413	1513			
491-	CSHEAR	35	3	1513	1413	1614	1714			
492-	CSHEAR	41	4	1300	1301	1502	1527			
493-	CSHEAR	42	4	1527	1502	1725	1726			
494-	CSHEAR	43	4	1311	1312	1513	1512			
495-	CSHEAR	44	4	1512	1513	1714	1715			
496-	CSHEAR	101	1	101	102	323	324			
497-	CSHEAR	102	1	102	103	322	323			
498-	CSHEAR	103	1	103	104	321	322			
499-	CSHEAR	104	1	104	105	320	321			
500-	CSHEAR	105	1	105	106	319	320			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
501-	CSHEAR	106	1	106	107	318	319			
502-	CSHEAR	107	1	107	108	317	318			
503-	CSHEAR	108	1	108	109	316	317			
504-	CSHEAR	109	1	109	110	315	316			
505-	CSHEAR	110	1	110	111	314	315			
506-	CSHEAR	300	2	300	200	416	527			
507-	CSHEAR	312	3	312	212	413	513			
508-	CSHEAR	315	1	315	314	515	516			
509-	CSHEAR	316	1	316	315	516	517			
510-	CSHEAR	317	1	317	316	517	518			
511-	CSHEAR	318	1	318	317	518	519			
512-	CSHEAR	319	1	319	318	519	520			
513-	CSHEAR	320	1	320	319	520	521			
514-	CSHEAR	321	1	321	320	521	522			
515-	CSHEAR	322	1	322	321	522	523			
516-	CSHEAR	323	1	323	322	523	524			
517-	CSHEAR	324	1	324	323	524	525			
518-	CSHEAR	400	2	400	300	527	627			
519-	CSHEAR	412	3	412	312	513	613			
520-	CSHEAR	500	2	500	400	627	727			
521-	CSHEAR	512	3	512	412	613	713			
522-	CSHEAR	513	3	513	413	614	714			
523-	CSHEAR	527	2	527	416	626	726			
524-	CSHEAR	600	2	600	500	727	827			
525-	CSHEAR	612	3	612	512	713	813			
526-	CSHEAR	613	3	613	513	714	814			
527-	CSHEAR	627	2	627	527	726	826			
528-	CSHEAR	700	2	700	600	827	927			
529-	CSHEAR	712	3	712	612	813	913			
530-	CSHEAR	713	3	713	613	814	914			
531-	CSHEAR	727	2	727	627	826	926			
532-	CSHEAR	800	2	800	700	927	1027			
533-	CSHEAR	812	3	812	712	913	1013			
534-	CSHEAR	813	3	813	713	914	1014			
535-	CSHEAR	827	2	827	727	926	1026			
536-	CSHEAR	900	2	900	800	1027	1127			
537-	CSHEAR	912	3	912	812	1013	1113			
538-	CSHEAR	913	3	913	813	1014	1114			
539-	CSHEAR	927	2	927	827	1026	1126			
540-	CSHEAR	1000	2	1000	900	1127	1227			
541-	CSHEAR	1012	3	1012	912	1113	1213			
542-	CSHEAR	1013	3	1013	913	1114	1214			
543-	CSHEAR	1027	2	1027	927	1126	1226			
544-	CSHEAR	1100	2	1100	1000	1227	1327			
545-	CSHEAR	1112	3	1112	1012	1213	1313			
546-	CSHEAR	1113	3	1113	1013	1214	1314			
547-	CSHEAR	1127	2	1127	1027	1226	1326			
548-	CSHEAR	1200	2	1200	1100	1327	1427			
549-	CSHEAR	1212	3	1212	1112	1313	1413			
550-	CSHEAR	1213	3	1213	1113	1314	1414			

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	1	2	3	4	5	6	7	8	9	10
551-	CSHEAR	1227	2	1227	1127	1326	1426			
552-	CSHEAR	1301	4	1301	1302	1503	1502			
553-	CSHEAR	1302	4	1302	1303	1504	1503			
554-	CSHEAR	1303	4	1303	1304	1505	1504			
555-	CSHEAR	1304	4	1304	1305	1506	1505			
556-	CSHEAR	1305	4	1305	1306	1507	1506			
557-	CSHEAR	1306	4	1306	1307	1508	1507			
558-	CSHEAR	1307	4	1307	1308	1509	1508			
559-	CSHEAR	1308	4	1308	1309	1510	1509			
560-	CSHEAR	1309	4	1309	1310	1511	1510			
561-	CSHEAR	1310	4	1310	1311	1512	1511			
562-	CSHEAR	1313	3	1313	1213	1414	1514			
563-	CSHEAR	1327	2	1327	1227	1426	1526			
564-	CSHEAR	1413	3	1413	1313	1514	1614			
565-	CSHEAR	1427	2	1427	1327	1526	1626			
566-	CSHEAR	1502	4	1502	1503	1724	1725			
567-	CSHEAR	1503	4	1503	1504	1723	1724			
568-	CSHEAR	1504	4	1504	1505	1722	1723			
569-	CSHEAR	1505	4	1505	1506	1721	1722			
570-	CSHEAR	1506	4	1506	1507	1720	1721			
571-	CSHEAR	1507	4	1507	1508	1719	1720			
572-	CSHEAR	1508	4	1508	1509	1718	1719			
573-	CSHEAR	1509	4	1509	1510	1717	1718			
574-	CSHEAR	1510	4	1510	1511	1716	1717			
575-	CSHEAR	1511	4	1511	1512	1715	1716			
576-	GRDSET							5		
577-	GRID	1		1.	-1.	2.		12346		
578-	GRID	2		1.	-1.	10.		12346		
579-	GRID	3		11.	-1.	2.		12346		
580-	GRID	4		11.	-1.	10.		12346		
581-	GRID	100				0.		0		
582-	GRID	101				1.		0		
583-	GRID	102				2.		0		
584-	GRID	103				3.		0		
585-	GRID	104				4.		0		
586-	GRID	105				5.		0		
587-	GRID	106				6.		0		
588-	GRID	107				7.		0		
589-	GRID	108				8.		0		
590-	GRID	109				9.		0		
591-	GRID	110				10.		0		
592-	GRID	111				11.				
593-	GRID	112				12.				
594-	GRID	200		1.		0.		35		
595-	GRID	201		1.		1.		5		
596-	GRID	202		1.		2.				
597-	GRID	203		1.		3.				
598-	GRID	204		1.		4.				
599-	GRID	205		1.		5.				
600-	GRID	206		1.		6.				

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                                         S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT      .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
  601-       GRID    207             1.              7.
  602-       GRID    208             1.              8.
  603-       GRID    209             1.              9.
  604-       GRID    210             1.              10.             5
  605-       GRID    211             1.              11.             5
  606-       GRID    212             1.              12.
  607-       GRID    300             2.0             0.
  608-       GRID    301             2.              1.
  609-       GRID    302             2.              2.
  610-       GRID    303             2.              3.
  611-       GRID    304             2.              4.
  612-       GRID    305             2.              5.
  613-       GRID    306             2.              6.
  614-       GRID    307             2.              7.
  615-       GRID    308             2.              8.
  616-       GRID    309             2.              9.
  617-       GRID    310             2.              10.
  618-       GRID    311             2.              11.
  619-       GRID    312             2.0             12.
  620-       GRID    313     2       2.              14.             456
  621-       GRID    314     2       2.              13.             0
  622-       GRID    315     2       2.              12.             0
  623-       GRID    316     2       2.              11.             0
  624-       GRID    317     2       2.              10.             0
  625-       GRID    318     2       2.              9.              0
  626-       GRID    319     2       2.              8.              0
  627-       GRID    320     2       2.              7.              0
  628-       GRID    321     2       2.              6.              0
  629-       GRID    322     2       2.              5.              0
  630-       GRID    323     2       2.              4.              0
  631-       GRID    324     2       2.              3.              0
  632-       GRID    325     2       2.              2.              456
  633-       GRID    400             3.0             0.
  634-       GRID    401             3.0             1.
  635-       GRID    402             3.0             2.
  636-       GRID    403             3.              3.
  637-       GRID    404             3.              4.
  638-       GRID    405             3.              5.
  639-       GRID    406             3.              6.
  640-       GRID    407             3.              7.
  641-       GRID    408             3.              8.
  642-       GRID    409             3.              9.
  643-       GRID    410             3.0             10.
  644-       GRID    411             3.0             11.
  645-       GRID    412             3.0             12.
  646-       GRID    413     2       3.0             14.
  647-       GRID    416     2       3.0             2.
  648-       GRID    500             4.0             0.
  649-       GRID    501             4.              1.
  650-       GRID    502             4.              2.
```

SORTED BULK DATA ECHO

CARD COUNT	1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
651-	GRID	503		4.		3.				
652-	GRID	504		4.		4.				
653-	GRID	505		4.		5.				
654-	GRID	506		4.		6.				
655-	GRID	507		4.		7.				
656-	GRID	508		4.		8.				
657-	GRID	509		4.		9.				
658-	GRID	510		4.		10.				
659-	GRID	511		4.		11.				
660-	GRID	512		4.	0	12.				
661-	GRID	513	2	4.	0	14.				
662-	GRID	514	4	4.		16.				
663-	GRID	515	4	4.		15.		0		
664-	GRID	516	4	4.		14.		0		
665-	GRID	517	4	4.		13.		0		
666-	GRID	518	4	4.		12.		0		
667-	GRID	519	4	4.		11.		0		
668-	GRID	520	4	4.		10.		0		
669-	GRID	521	4	4.		9.		0		
670-	GRID	522	4	4.		8.		0		
671-	GRID	523	4	4.		7.		0		
672-	GRID	524	4	4.		6.		0		
673-	GRID	525	4	4.		5.		0		
674-	GRID	526	4	4.		4.				
675-	GRID	527	2	4.	0	2.				
676-	GRID	600		5.	0	0.				
677-	GRID	601		5.	0	1.				
678-	GRID	602		5.	0	2.				
679-	GRID	603		5.		3.				
680-	GRID	604		5.		4.				
681-	GRID	605		5.		5.				
682-	GRID	606		5.		6.				
683-	GRID	607		5.		7.				
684-	GRID	608		5.		8.				
685-	GRID	609		5.		9.				
686-	GRID	610		5.	0	10.				
687-	GRID	611		5.	0	11.				
688-	GRID	612		5.	0	12.				
689-	GRID	613	2	5.	0	14.				
690-	GRID	614	4	5.	0	16.				
691-	GRID	615	4	5.		15.				
692-	GRID	616	4	5.		14.				
693-	GRID	617	4	5.		13.				
694-	GRID	618	4	5.		12.				
695-	GRID	619	4	5.		11.				
696-	GRID	620	4	5.		10.				
697-	GRID	621	4	5.		9.				
698-	GRID	622	4	5.		8.				
699-	GRID	623	4	5.		7.				
700-	GRID	624	4	5.		6.				

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                                   S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT           1   ..   2   ..   3   ..   4   ..   5   ..   6   ..   7   ..   8   ..   9   ..   10  .
 701-           GRID    625     4       5.              5.
 702-           GRID    626     4       5.0             4.
 703-           GRID    627     2       5.              2.
 704-           GRID    700             6.0             0.
 705-           GRID    701             6.              1.
 706-           GRID    702             6.              2.
 707-           GRID    703             6.              3.
 708-           GRID    704             6.              4.
 709-           GRID    705             6.              5.
 710-           GRID    706             6.              6.
 711-           GRID    707             6.              7.
 712-           GRID    708             6.              8.
 713-           GRID    709             6.              9.
 714-           GRID    710             6.              10.
 715-           GRID    711             6.              11.
 716-           GRID    712             6.0             12.
 717-           GRID    713     2       6.0             14.
 718-           GRID    714     4       6.0             16.
 719-           GRID    715     4       6.              15.
 720-           GRID    716     4       6.              14.
 721-           GRID    717     4       6.              13.
 722-           GRID    718     4       6.              12.
 723-           GRID    719     4       6.              11.
 724-           GRID    720     4       6.              10.
 725-           GRID    721     4       6.              9.
 726-           GRID    722     4       6.              8.
 727-           GRID    723     4       6.              7.
 728-           GRID    724     4       6.              6.
 729-           GRID    725     4       6.              5.
 730-           GRID    726     4       6.0             4.
 731-           GRID    727     2       6.0             2.
 732-           GRID    800             7.0             0.
 733-           GRID    801             7.0             1.
 734-           GRID    802             7.0             2.
 735-           GRID    803             7.              3.
 736-           GRID    804             7.              4.
 737-           GRID    805             7.              5.
 738-           GRID    806             7.              6.
 739-           GRID    807             7.              7.
 740-           GRID    808             7.              8.
 741-           GRID    809             7.              9.
 742-           GRID    810             7.0             10.
 743-           GRID    811             7.0             11.
 744-           GRID    812             7.0             12.
 745-           GRID    813     2       7.0             14.
 746-           GRID    814     4       7.0             16.
 747-           GRID    815     4       7.              15.
 748-           GRID    816     4       7.              14.
 749-           GRID    817     4       7.              13.
 750-           GRID    818     4       7.              12.
```

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT   1 .. 2 .. 3 .. 4 .. 5 .. 6 .. 7 .. 8 .. 9 .. 10 .

751-	GRID	819	4	7.		11.
752-	GRID	820	4	7.		10.
753-	GRID	821	4	7.		9.
754-	GRID	822	4	7.		8.
755-	GRID	823	4	7.		7.
756-	GRID	824	4	7.		6.
757-	GRID	825	4	7.		5.
758-	GRID	826	4	7.	0	4.
759-	GRID	827	2	7.	0	2.
760-	GRID	900		8.	0	0.
761-	GRID	901		8.		1.
762-	GRID	902		8.		2.
763-	GRID	903		8.		3.
764-	GRID	904		8.		4.
765-	GRID	905		8.		5.
766-	GRID	906		8.		6.
767-	GRID	907		8.		7.
768-	GRID	908		8.		8.
769-	GRID	909		8.		9.
770-	GRID	910		8.		10.
771-	GRID	911		8.		11.
772-	GRID	912		8.	0	12.
773-	GRID	913	2	8.	0	14.
774-	GRID	914	4	8.	0	16.
775-	GRID	915	4	8.		15.
776-	GRID	916	4	8.		14.
777-	GRID	917	4	8.		13.
778-	GRID	918	4	8.		12.
779-	GRID	919	4	8.		11.
780-	GRID	920	4	8.		10.
781-	GRID	921	4	8.		9.
782-	GRID	922	4	8.		8.
783-	GRID	923	4	8.		7.
784-	GRID	924	4	8.		6.
785-	GRID	925	4	8.		5.
786-	GRID	926	4	8.	0	4.
787-	GRID	927	2	8.	0	2.
788-	GRID	1000		9.	0	0.
789-	GRID	1001		9.		1.
790-	GRID	1002		9.		2.
791-	GRID	1003		9.		3.
792-	GRID	1004		9.		4.
793-	GRID	1005		9.		5.
794-	GRID	1006		9.		6.
795-	GRID	1007		9.		7.
796-	GRID	1008		9.		8.
797-	GRID	1009		9.		9.
798-	GRID	1010		9.		10.
799-	GRID	1011		9.		11.
800-	GRID	1012		9.	0	12.

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 .. 8 .. 9 .. 10 .
801-	GRID	1013	2	9.0	14.		
802-	GRID	1014	4	9.0	16.		
803-	GRID	1015	4	9.	15.		
804-	GRID	1016	4	9.	14.		
805-	GRID	1017	4	9.	13.		
806-	GRID	1018	4	9.	12.		
807-	GRID	1019	4	9.	11.		
808-	GRID	1020	4	9.	10.		
809-	GRID	1021	4	9.	9.		
810-	GRID	1022	4	9.	8.		
811-	GRID	1023	4	9.	7.		
812-	GRID	1024	4	9.	6.		
813-	GRID	1025	4	9.	5.		
814-	GRID	1026	4	9.0	4.		
815-	GRID	1027	2	9.0	2.		
816-	GRID	1100		10.	0.		
817-	GRID	1101		10.	1.		
818-	GRID	1102		10.	2.		
819-	GRID	1103		10.	3.		
820-	GRID	1104		10.	4.		
821-	GRID	1105		10.	5.		
822-	GRID	1106		10.	6.		
823-	GRID	1107		10.	7.		
824-	GRID	1108		10.	8.		
825-	GRID	1109		10.	9.		
826-	GRID	1110		10.	10.		
827-	GRID	1111		10.	11.		
828-	GRID	1112		10.	12.		
829-	GRID	1113	2	10.0	14.		
830-	GRID	1114	4	10.	16.		
831-	GRID	1115	4	10.	15.		
832-	GRID	1116	4	10.	14.		
833-	GRID	1117	4	10.	13.		
834-	GRID	1118	4	10.	12.		
835-	GRID	1119	4	10.	11.		
836-	GRID	1120	4	10.	10.		
837-	GRID	1121	4	10.	9.		
838-	GRID	1122	4	10.	8.		
839-	GRID	1123	4	10.	7.		
840-	GRID	1124	4	10.	6.		
841-	GRID	1125	4	10.	5.		
842-	GRID	1126	4	10.	4.		
843-	GRID	1127	2	10.0	2.		
844-	GRID	1200		11.	0.		
845-	GRID	1201		11.	1.		15 5
846-	GRID	1202		11.	2.		
847-	GRID	1203		11.	3.		
848-	GRID	1204		11.	4.		
849-	GRID	1205		11.	5.		
850-	GRID	1206		11.	6.		

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
851-	GRID	1207		11.		7.				
852-	GRID	1208		11.		8.				
853-	GRID	1209		11.		9.				
854-	GRID	1210		11.		10.		5		
855-	GRID	1211		11.		11.		15		
856-	GRID	1212		11.		12.				
857-	GRID	1213	2	11. 0		14.				
858-	GRID	1214	4	11.		16.				
859-	GRID	1215	4	11.		15.				
860-	GRID	1216	4	11.		14.				
861-	GRID	1217	4	11.		13.				
862-	GRID	1218	4	11.		12.				
863-	GRID	1219	4	11.		11.				
864-	GRID	1220	4	11.		10.				
865-	GRID	1221	4	11.		9.				
866-	GRID	1222	4	11.		8.				
867-	GRID	1223	4	11.		7.				
868-	GRID	1224	4	11.		6.				
869-	GRID	1225	4	11.		5.				
870-	GRID	1226	4	11.		4.				
871-	GRID	1227	2	11. 0		2.				
872-	GRID	1300		12.		0.				
873-	GRID	1301		12.		1.		0		
874-	GRID	1302		12.		2.		0		
875-	GRID	1303		12.		3.		0		
876-	GRID	1304		12.		4.		0		
877-	GRID	1305		12.		5.		0		
878-	GRID	1306		12.		6.		0		
879-	GRID	1307		12.		7.		0		
880-	GRID	1308		12.		8.		0		
881-	GRID	1309		12.		9.		0		
882-	GRID	1310		12.		10.		0		
883-	GRID	1311		12.		11.		0		
884-	GRID	1312		12.		12.				
885-	GRID	1313	2	12. 0		14.				
886-	GRID	1314	4	12.		16.				
887-	GRID	1315	4	12.		15.				
888-	GRID	1316	4	12.		14.				
889-	GRID	1317	4	12.		13.				
890-	GRID	1318	4	12.		12.				
891-	GRID	1319	4	12.		11.				
892-	GRID	1320	4	12.		10.				
893-	GRID	1321	4	12.		9.				
894-	GRID	1322	4	12.		8.				
895-	GRID	1323	4	12.		7.				
896-	GRID	1324	4	12.		6.				
897-	GRID	1325	4	12.		5.				
898-	GRID	1326	4	12.		4.				
899-	GRID	1327	2	12. 0		2.				
900-	GRID	1413	2	13. 0		14.				

S O R T E D   B U L K   D A T A   E C H O

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CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 901-        GRID    1414    4       13.             16.
 902-        GRID    1415    4       13.             15.
 903-        GRID    1416    4       13.             14.
 904-        GRID    1417    4       13.             13.
 905-        GRID    1418    4       13.             12.
 906-        GRID    1419    4       13.             11.
 907-        GRID    1420    4       13.             10.
 908-        GRID    1421    4       13.             9.
 909-        GRID    1422    4       13.             3.
 910-        GRID    1423    4       13.             7.
 911-        GRID    1424    4       13.             6.
 912-        GRID    1425    4       13.             5.
 913-        GRID    1426    4       13.             4.
 914-        GRID    1427    2       13. 0           2.
 915-        GRID    1502    2       14.             3.                      0
 916-        GRID    1503    2       14.             4.                      0
 917-        GRID    1504    2       14.             5.                      0
 918-        GRID    1505    2       14.             6.                      0
 919-        GRID    1506    2       14.             7.                      0
 920-        GRID    1507    2       14.             8.                      0
 921-        GRID    1508    2       14.             9.                      0
 922-        GRID    1509    2       14.             10.                     0
 923-        GRID    1510    2       14.             11.                     0
 924-        GRID    1511    2       14.             12.                     0
 925-        GRID    1512    2       14.             13.                     0
 926-        GRID    1513    2       14.             14.                     456
 927-        GRID    1514    4       14.             16.
 928-        GRID    1515    4       14.             15.
 929-        GRID    1516    4       14.             14.
 930-        GRID    1517    4       14.             13.
 931-        GRID    1518    4       14.             12.
 932-        GRID    1519    4       14.             11.
 933-        GRID    1520    4       14.             10.
 934-        GRID    1521    4       14.             9.
 935-        GRID    1522    4       14.             8.
 936-        GRID    1523    4       14.             7.
 937-        GRID    1524    4       14.             6.
 938-        GRID    1525    4       14.             5.
 939-        GRID    1526    4       14.             4.
 940-        GRID    1527    2       14.             2.                      456
 941-        GRID    1614    4       15.             16.
 942-        GRID    1615    4       15.             15.
 943-        GRID    1616    4       15.             14.
 944-        GRID    1617    4       15.             13.
 945-        GRID    1618    4       15.             12.
 946-        GRID    1619    4       15.             11.
 947-        GRID    1620    4       15.             10.
 948-        GRID    1621    4       15.             9.
 949-        GRID    1622    4       15.             8.
 950-        GRID    1623    4       15.             7.
```

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	1	2	3	4	5	6	7	8	9	10
951-	GRID	1624	4	15.		6.				
952-	GRID	1625	4	15.		5.				
953-	GRID	1626	4	15.		4.				
954-	GRID	1714	4	16.		16.				
955-	GRID	1715	4	16.		15.		0		
956-	GRID	1716	4	16.		14.		0		
957-	GRID	1717	4	16.		13.		0		
958-	GRID	1718	4	16.		12.		0		
959-	GRID	1719	4	16.		11.		0		
960-	GRID	1720	4	16.		10.		0		
961-	GRID	1721	4	16.		9.		0		
962-	GRID	1722	4	16.		8.		0		
963-	GRID	1723	4	16.		7.		0		
964-	GRID	1724	4	16.		6.		0		
965-	GRID	1725	4	16.		5.		0		
966-	GRID	1726	4	16.		4.				
967-	MAT1	10	30. 6+6		.3		6. 30-6	78.		
968-	MAT1	11		50. 0+3	.3			78.		
969-	MAT1	100	16. 0+6		.31		4. 90-6	78.		
970-	MAT1	101		.7+5	.3			78.		
971-	MAT1	111	1. 4+4		.3					
972-	MATT1	10	1				2			
973-	MATT1	11		3						
974-	MATT1	100	4				5			
975-	MATT1	101		6						
976-	PBAR	1	10	.0028	1. 00-9	3. 75-6	1. 00-9			
977-	PBAR	2	10	.0028	3. 75-6	1. 00-9	1. 00-9			
978-	PLOAD2	10	2.	615	THRU	626				
979-	PLOAD2	10	2.	715	THRU	726				
980-	PLOAD2	10	2.	815	THRU	826				
981-	PLOAD2	10	2.	915	THRU	926				
982-	PLOAD2	10	2.	1015	THRU	1026				
983-	PLOAD2	10	2.	1115	THRU	1126				
984-	PLOAD2	10	2.	1215	THRU	1226				
985-	PLOAD2	10	2.	1315	THRU	1326				
986-	PLOAD2	10	2.	1415	THRU	1426				
987-	PLOAD2	10	2.	1515	THRU	1526				
988-	PLOAD2	10	2.	1615	THRU	1626				
989-	PLOAD2	10	2.	515	THRU	526				
990-	PROD	1	111	.050	.000398					
991-	PROD	3	10	.0028	3. 75-6					
992-	PSHEAR	1	10	.0028						
993-	PSHEAR	2	10	.0028						
994-	PSHEAR	3	10	.0028						
995-	PSHEAR	4	10	.0028						
996-	PSHELL	5	10	.0100	10	2437. 2	11	28.		+P5
997-	+P5	-. 145	.145							
998-	PSHELL	6	100	.006	100	2494. 4	101	28. 33		+P6
999-	+P6	-. 0880	.0880							
1000-	PSHELL	60	100	.012	100	645. 56	101	14. 17		+P60

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	1	2	3	4	5	6	7	8	9	10
1001-	+P60	-.0910	.0910							
1002-	PSHELL	600	100	.009	100	1127.6	101	18.89		+P600
1003-	+P600	-.0895	.0895							
1004-	TABLEM1	1								+L1
1005-	+L1	78.0	31.6+6	200.	30.+6	400.	27.5+6	600.	25.0+6	+L2
1006-	+L2	800.	22.7+6	1000.	20.3+6	1200.	17.7+6	1400.	15.3+6	+L3
1007-	+L3	1600.	12.9+6	1800.	10.5+6	2000.	2.8+6	ENDT		
1008-	TABLEM1	2								+L10
1009-	+L10	78.0	6.3-6	200.	6.4-6	400.	7.0-6	600.	7.4-6	+L11
1010-	+L11	800.0	7.6-6	1000.	7.7-6	1200.	8.0-6	1400.	8.4-6	+L12
1011-	+L12	1600.	8.7-6	1800.	9.0-6	2000.	9.2-6	ENDT		
1012-	TABLEM1	3								+LAB110
1013-	+LAB110	78.0	50.0+3	200.	49.2+3	400.	47.5+3	600.	45.8+3	+LAB111
1014-	+LAB111	800.	44.1+3	1000.	41.9+3	1200.	40.3+3	1400.	38.1+3	+LAB112
1015-	+LAB112	1600.	35.6+3	1800.	33.1+3	2000.	30.1+3	ENDT		
1016-	TABLEM1	4								+LA1
1017-	+LA1	78.	16.+6	850.	11.8+6	1000.	8.+6	ENDT		
1018-	TABLEM1	5								+LAB50
1019-	+LAB50	78.	4.9-6	500.	5.3-6	1000.	5.6-6	ENDT		
1020-	TABLEM1	6								+LABL1
1021-	+LABL1	78.	.7+5	200.	5.88+4	400.	4.9+4	1000.	3.15+4	+LABL2
1022-	+LABL2	ENDT								
1023-	TEMP	1	313	375.	1513	375.				
1024-	TEMP	1	314	375.	416	375.				
1025-	TEMP	1	315	375.	527	375.				
1026-	TEMP	1	316	375.	627	375.				
1027-	TEMP	1	317	375.	727	375.				
1028-	TEMP	1	318	375.	827	375.				
1029-	TEMP	1	319	375.	927	375.				
1030-	TEMP	1	320	375.	1027	375.				
1031-	TEMP	1	321	375.	1127	375.				
1032-	TEMP	1	322	375.	1227	375.				
1033-	TEMP	1	323	375.	1327	375.				
1034-	TEMP	1	324	375.	1427	375.				
1035-	TEMP	1	325	375.	1527	375.				
1036-	TEMP	1	413	375.	1512	375.				
1037-	TEMP	1	513	375.	1511	375.				
1038-	TEMP	1	515	650.	1715	650.				
1039-	TEMP	1	516	650.	1716	650.				
1040-	TEMP	1	517	650.	1717	650.				
1041-	TEMP	1	518	650.	1718	650.				
1042-	TEMP	1	519	650.	1719	650.				
1043-	TEMP	1	520	650.	1720	650.				
1044-	TEMP	1	521	650.	1721	650.				
1045-	TEMP	1	522	650.	1722	650.				
1046-	TEMP	1	523	650.	1723	650.				
1047-	TEMP	1	524	650.	1724	650.				
1048-	TEMP	1	525	650.	1725	650.				
1049-	TEMP	1	526	650.	514	650.				
1050-	TEMP	1	613	375.	1510	375.				

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 .. 7 .. 8 .. 9 .. 10 .
1051-	TEMP	1	626	650.	614	650.
1052-	TEMP	1	713	375.	1509	375.
1053-	TEMP	1	726	650.	714	650.
1054-	TEMP	1	813	375.	1508	375.
1055-	TEMP	1	826	650.	814	650.
1056-	TEMP	1	913	375.	1507	375.
1057-	TEMP	1	926	650.	914	650.
1058-	TEMP	1	1013	375.	1506	375.
1059-	TEMP	1	1026	650.	1014	650.
1060-	TEMP	1	1113	375.	1505	375.
1061-	TEMP	1	1126	650.	1114	650.
1062-	TEMP	1	1213	375.	1504	375.
1063-	TEMP	1	1226	650.	1214	650.
1064-	TEMP	1	1313	375.	1503	375.
1065-	TEMP	1	1326	650.	1314	650.
1066-	TEMP	1	1413	375.	1502	375.
1067-	TEMP	1	1426	650.	1414	650.
1068-	TEMP	1	1526	650.	1514	650.
1069-	TEMP	1	1626	650.	1614	650.
1070-	TEMP	1	1726	650.	1714	650.
1071-	TEMP	2	313	1066.	1513	1066.
1072-	TEMP	2	314	1066.	416	1066.
1073-	TEMP	2	315	1066.	527	1066.
1074-	TEMP	2	316	1066.	627	1066.
1075-	TEMP	2	317	1066.	727	1066.
1076-	TEMP	2	318	1066.	827	1066.
1077-	TEMP	2	319	1066.	927	1066.
1078-	TEMP	2	320	1066.	1027	1066.
1079-	TEMP	2	321	1066.	1127	1066.
1080-	TEMP	2	322	1066.	1227	1066.
1081-	TEMP	2	323	1066.	1327	1066.
1082-	TEMP	2	324	1066.	1427	1066.
1083-	TEMP	2	325	1066.	1527	1066.
1084-	TEMP	2	413	1066.	1512	1066.
1085-	TEMP	2	513	1066.	1511	1066.
1086-	TEMP	2	515	1900.	1715	1900.
1087-	TEMP	2	516	1900.	1716	1900.
1088-	TEMP	2	517	1900.	1717	1900.
1089-	TEMP	2	518	1900.	1718	1900.
1090-	TEMP	2	519	1900.	1719	1900.
1091-	TEMP	2	520	1900.	1720	1900.
1092-	TEMP	2	521	1900.	1721	1900.
1093-	TEMP	2	522	1900.	1722	1900.
1094-	TEMP	2	523	1900.	1723	1900.
1095-	TEMP	2	524	1900.	1724	1900.
1096-	TEMP	2	525	1900.	1725	1900.
1097-	TEMP	2	526	1900.	514	1900.
1098-	TEMP	2	613	1066.	1510	1066.
1099-	TEMP	2	626	1900.	614	1900.
1100-	TEMP	2	713	1066.	1509	1066.

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
1101-	TEMP	2	726	1900.	714	1900.				
1102-	TEMP	2	813	1066.	1508	1066.				
1103-	TEMP	2	826	1900.	814	1900.				
1104-	TEMP	2	913	1066.	1507	1066.				
1105-	TEMP	2	926	1900.	914	1900.				
1106-	TEMP	2	1013	1066.	1506	1066.				
1107-	TEMP	2	1026	1900.	1014	1900.				
1108-	TEMP	2	1113	1066.	1505	1066.				
1109-	TEMP	2	1126	1900.	1114	1900.				
1110-	TEMP	2	1213	1066.	1504	1066.				
1111-	TEMP	2	1226	1900.	1214	1900.				
1112-	TEMP	2	1313	1066.	1503	1066.				
1113-	TEMP	2	1326	1900.	1314	1900.				
1114-	TEMP	2	1413	1066.	1502	1066.				
1115-	TEMP	2	1426	1900.	1414	1900.				
1116-	TEMP	2	1526	1900.	1514	1900.				
1117-	TEMP	2	1626	1900.	1614	1900.				
1118-	TEMP	2	1726	1900.	1714	1900.				
1119-	TEMPD	1	100.							
1120-	TEMPD	2	208.							
1121-	TEMPP1	1	100	100.	0.	100.	100.			+TT1
1122-	+TT1	101	THRU	111	1200	THRU	1211			+TT2
1123-	+TT2	200	300	400	500	600	700			+TT3
1124-	+TT3	800	900	1000	1100	211	311			+TT4
1125-	+TT4	411	511	611	711	811	911			+TT5
1126-	+TT5	1011	1111							
1127-	TEMPP1	1	201	100.	0.	100.	100.			+TT10
1128-	+TT10	202	THRU	210	1101	THRU	1110			+TT20
1129-	+TT20	301	401	501	601	701	801			+TT30
1130-	+TT30	901	1001	310	410	510	610			+TT40
1131-	+TT40	710	810	910	1010					
1132-	TEMPP1	1	302	100.	0.	100.	100.			+TT100
1133-	+TT100	303	THRU	309	702	THRU	709			+TT200
1134-	+TT200	402	THRU	409	802	THRU	809			+TT300
1135-	+TT300	502	THRU	509	902	THRU	909			+TT400
1136-	+TT400	602	THRU	609	1002	THRU	1009			
1137-	TEMPP1	1	515	625.	175.4	600.	650.			+T1
1138-	+T1	516	THRU	526	615	THRU	626			+T2
1139-	+T2	715	THRU	726	815	THRU	826			+T3
1140-	+T3	1015	THRU	1026	1115	THRU	1126			+T4
1141-	+T4	1215	THRU	1226	1315	THRU	1326			+T5
1142-	+T5	1415	THRU	1426	1515	THRU	1526			+T6
1143-	+T6	1615	THRU	1626	915	THRU	926			
1144-	TEMPP1	2	100	220.	136.4	208.	232.			+WT1
1145-	+WT1	101	THRU	111	1200	THRU	1211			+WT2
1146-	+WT2	200	300	400	500	600	700			+WT3
1147-	+WT3	800	900	1000	1100	211	311			+WT4
1148-	+WT4	411	511	611	711	811	911			+WT5
1149-	+WT5	1011	1111							
1150-	TEMPP1	2	201	220.	137.5	203.	232.			+WT10

```
                                  S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
1151-          +WT10   202     THRU    210     1101    THRU    1110                    +WT20
1152-          +WT20   301     401     501     601     701     801                     +WT30
1153-          +WT30   901     1001    310     410     510     610                     +WT40
1154-          +WT40   710     810     910     1010
1155-          TEMPP1  2       302     220.    138.7   208.    232.                    +WT100
1156-          +WT100  303     THRU    309     702     THRU    709                     +WT200
1157-          +WT200  402     THRU    409     802     THRU    809                     +WT300
1158-          +WT300  502     THRU    509     902     THRU    909                     +WT400
1159-          +WT400  602     THRU    609     1002    THRU    1009
1160-          TEMPP1  2       515     1884.5  108.8   1869.   1900.                   +W1
1161-          +W1     516     THRU    526     615     THRU    626                     +W2
1162-          +W2     715     THRU    726     815     THRU    826                     +W3
1163-          +W3     1015    THRU    1026    1115    THRU    1126                    +W4
1164-          +W4     1215    THRU    1226    1315    THRU    1326                    +W5
1165-          +W5     1415    THRU    1426    1515    THRU    1526                    +W6
1166-          +W6     1615    THRU    1626    915     THRU    926
               ENDDATA

          TOTAL COUNT=  1167
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15. Supplementary Notes

Langley Technical Monitor: John Shideler
Interim Report

16. Abstract

High temperature materials were surveyed, and Inconel 617 and titanium were selected for application to a honeycomb TPS configuration designed to withstand 2000^{o} F. The configuration was analyzed both thermally and structurally. Component and full sized panels were fabricated and tested to obtain data for comparison with analysis. Results verified the panel design. Twenty five panels were delivered to NASA Langley Research Center for additional evaluation.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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